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RESTRICTED

THE ROYAL RADAR ESTABLISHMENT

J. E. N. Hooper, B.Sc.

The Royal Radar Establishment grew out of the team set up at Bawdsey (Suffolk) in 1935 under Mr. (now Sir) Robert Watson Watt to develop the potential of R.D.F. The end of World War II found two radar establishments in Malvern—the Telecommunications Research Establishment, concerned with radar developments of special interest to the R.A.F. and the Radar Research and Development Establishment with those for the Army. These two Establishments were amalgamated in 1953 to form the Radar Research Establishment and since 1957 when Her Majesty the Queen visited the Establishment and bestowed upon it the title of "Royal", the initials have come to stand for the words in the title of this article.

The Establishment currently comprises two main Technical Departments—the Physics and Electronics Department and the Military and Civil Systems Department—both concentrated, though not wholly, at the South Site in St. Andrews Road.

In addition to these two Technical Departments there are three supporting Departments. The Engineering Department, comprising Workshops and Drawing Office, exists to design and manufacture such experimental equipment as is required in the laboratories and is equipped with an almost unique variety of machine tools and processes. The Aircraft Department, which is housed at an airfield at Pershore, some 20 miles from Malvern, operates a fleet of aircraft in which experimental equipment is fitted and flown. The Department has considerable facilities for carrying out not only installation work but modifications, where necessary, to aircraft structure to accommodate, for instance, unusual aerials. The Administration Department exists to free so far as possible, the scientists from purely administrative work and covers a wide variety of services including security, stores provisioning, *etc.*

Associated with R.R.E. is the College of Electronics which holds a distinguished position in the field of education in electronic techniques. Its chief function is the training of both Craft and Technician Apprentices and it also holds induction courses for new entrants to R.R.E. and specialist electronics courses for staff from all parts of the Ministry. Under the aegis of the Local Education Authority, the College holds evening and day continuation classes to a curriculum which has a strong electronics bias.

Current Work

The Military and Civil Systems Department comprises three Groups: Ground Radar and Air Traffic Control, Airborne Radar, and Guided Weapons.

Ground Radar and Air Traffic Control Group

This Group is responsible for radar techniques research and data processing systems for ground surveillance purposes of a wide variety—for defence purposes, for application to air traffic control and for the Field Army. Much of the scientific effort of the Group is devoted to the study and development of radar techniques to improve the capabilities of radar for surveillance. These studies cover such aspects as the suppression or elimination of " clutter " by the use of suitable forms of modulation or radiation polarisation, the achievement of optimum discrimination by, for example, pulse compression techniques, the study of aerial problems and the devising of satisfactory three dimensional radar systems. Coupled with all this is research into means of developing more fully automatic radars in which the signal information can be extracted without the use of a human observer in the usual sense.

This leads on naturally to a whole range of data handling studies and investigations in which automatic digital computers are applied to the processing of the radar-derived data. The radar data is thereby stored and handled in a form which makes possible rapid and accurate correlation with other sources of information. Thus in the realms of A.T.C. it becomes possible to correlate radar positional information with flight plans and procedural information in a way that can be vastly speedier and more accurate than is possible by using purely human data processors. This data processing exchange will be the core of an integrated air defence and air traffic control radar surveillance system now coming into being which will be one of the largest of its kind.

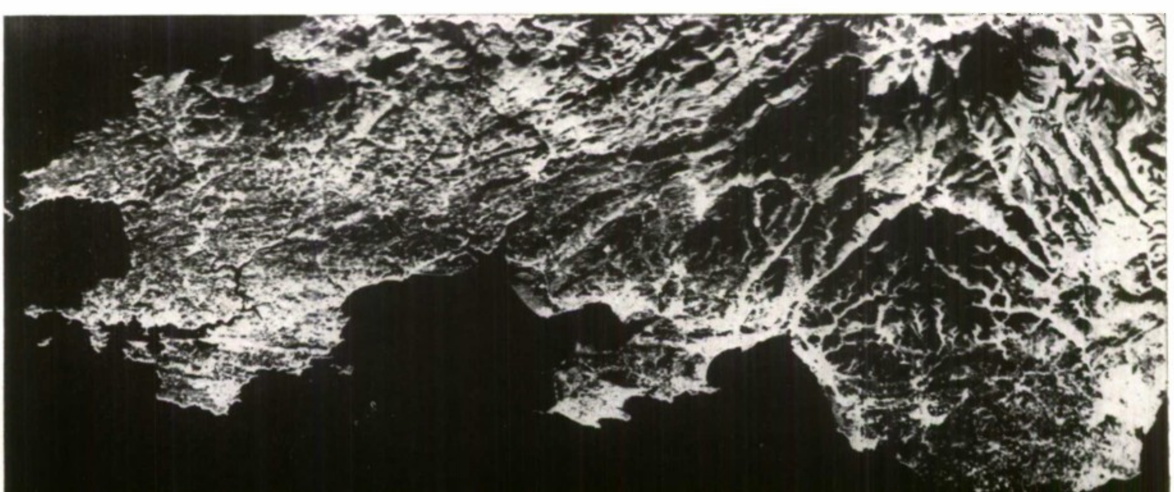
In mobile tactical operations, both the Army and the R.A.F. require highly mobile surveillance radar systems for many purposes, ranging from the detection of enemy units and vehicles on the ground and in the air, to the location of opposing offensive weapons such as mortars. The Group is concerned with the development of radars for such purposes and this leads to the investigation of techniques capable of meeting the exacting demands of light weight and high mobility, yet with adequate range and accuracy.

As is the case with the Establishment as a whole, the Group maintains the closest contact with its " customers ", the Army and the R.A.F. on the military side and the Air Traffic Control Service on the civil, and this close collaboration between user and research is, and always has been, an important characteristic of the laboratory.

Airborne Radar Group

This Group is responsible for research and development aspects of airborne radar equipments for navigation, search, attack and reconnaissance for both the R.A.F. and the Fleet Air Arm. It also has the responsibility for the guidance of air-to-air guided missiles.

Navigation radars include those for doppler navigation, forward and sideways looking radars for ground mapping, and terrain-following radars. Many of these applications require detailed knowledge of the characteristics of the ground and



A picture of S.W. Wales obtained by sideways looking radar, obtainable by night or day and through cloud.

Portable radar for detection of movement in clutter. It uses pulse doppler techniques with visual and aural presentation.

identifiable features of the ground, and involve a great deal of flying of experimental equipment which is accomplished with the co-operation of the Aircraft Department at Pershore.

The problems involved in identifying sufficiently small areas of ground, for spot measurements to be made, lead to obtaining satisfactory aerial designs which are compatible with the structural and aerodynamic requirements of modern high speed aircraft, and a high degree of range resolution such as may be achieved by pulse compression techniques.

In the field of search and attack radars for airborne interception, the need to detect low flying aircraft against a background of ground or sea " clutter " has necessitated the development of coherent radar techniques.

Reconnaissance systems often make use of sideways looking radar. Here, and also in connection with optical reconnaissance techniques, the necessity to present data visually in the aircraft within a few seconds of its being obtained, has led to the development of rapid photographic processing techniques.

The development of infra-red cells and the necessary cooling systems for use in the guidance of some air-to-air missiles is undertaken in association with the Physics Group and some work is in hand to investigate the use of lasers for accurate ranging purposes.

With the ever increasing complexity of equipment the necessity for high reliability, light weight and small size, of particular importance for airborne applications, has given enormous impetus to the use of micro-electronic circuit techniques and these are being pursued vigorously for a variety of applications.

Guided Weapons Group

This Group makes its major technical contribution in the applications of electronics to the G.W. field, notably to defensive surface-to-air missile systems.

The designs of suitable acquisition radars, of tracking radars, of target illuminators and of missile homing systems constitute problems in which the Group takes a detailed responsibility. Since the accuracy of a guidance system so often depends on the complex radar characteristics of the reflecting target, a thorough study has been made of the effect of the ever changing target echoes with aspect using a simulator in which parameters of the target and of the homing missile can be varied, thereby eliminating much of the expensive trials work that would otherwise be necessary.

The final stage in a G.W. engagement may demand a proximity fuse and both radar and infra-red techniques are studied to this end.

The sometimes conflicting requirements of a G.W. radar in its alternative rôles of target acquisition and tracking are leading to the study of an adaptive radar in which the modulation waveform, the aerial scanning pattern and thus the data rate, and other parameters can be automatically adjusted for optimum performance.

A modern 3-dimensional radar aerial for use in tracking aircraft movements for Defence and Traffic Control purposes.

Such variability must be computer controlled and the necessary techniques of CW operation, of electronic scanning and data processing are being studied.

In the complete weapon system integration rôle the Group makes a further significant contribution in maintaining a balance between conflicting factors to achieve an optimum solution. One important way of helping to achieve the correct initial balance is to study the effect of changes on overall system performance, taking into account both operational and technical factors, and here the R.R.E. Assessment Division works closely with the Group. Many specialist areas in which R.R.E. is not directly engaged—such as propulsion, aerodynamics, explosives, *etc.*—are involved and here the Group is often called upon to act as a co-ordinating authority to achieve an integrated solution with the help of other Research Establishments and of Industry.

A need for high precision tracking radars necessarily using large aerials has highlighted conflicting interactions between the structural, servo and microwave problems. As a test facility for studying these problems, an experimental 45 foot diameter aerial has been constructed and this facility is being used for tracking satellites. The aerial is set to "follow" a predicted orbit to which, however, it will automatically record corrections in the light of the actual track from which successive trajectories can be more accurately computed.

45ft. diameter precision radar tracking aerial.

The Physics and Electronics Department comprises two Groups: Physics and Electronics.

Physics Group

The Group concentrates its attention almost wholly on the study at a quite fundamental level, of materials and phenomena upon which the future of electronics is likely to depend. Originally effort was concentrated upon materials of potential military use in the field of infra-red techniques, but current studies now embrace the solid state physics field quite widely.

A considerable effort is devoted to the preparation of single crystals of a wide variety of materials, both semiconductors (Si, Ge, InSb, GaAs) and suitably impurity doped crystals for use as lasers ($CaWO_4$, CaF_2, Yttrium Aluminium Garnet, *etc.*). This has called for the development of very special techniques both in the preparation of crystals and in assessing the quality of the product, and chemists and metallurgists in addition to physicists contribute to this work.

Much of the fundamental work in the field of solid state crystals, especially in the development of infra-red detectors, necessitated an environment of very low temperature and high magnetic fields. The Group has its own hydrogen and helium liquefaction facilities and has developed a facility for providing a steady magnetic field in excess of 130 KOe, which is unique in U.K.

Current work also includes the development of thin magnetic film techniques for possible use as storage elements in computers, and an investigation of the electro optical properties of certain materials.

From earlier paragraphs it will have been clear that digital computing techniques pervade almost the whole of the Establishment's work. In the Physics Group, a small number of staff is concerned with advanced programming research which will have repercussions upon the logical design of future computers and which is already leading to the automatic compilation of compilers and to new query languages which will greatly facilitate information retrieval.

Electronics Group

The function of the Electronics Group is to act as a link between the basic research work of the Physics Group and the Military and Civil Systems Department, and to concentrate on those techniques expected to be needed in future projects.

Considerable effort is devoted to techniques which contribute to the development of microcircuits, both thin film circuits and integrated solid circuits. In parallel, the associated problems of circuit design in which these microcircuits can be efficiently employed are being pursued for both linear and digital circuits.

Some effort is still devoted to developments of conventional components and a wide range of facilities is available for the environmental testing of complete equipments.

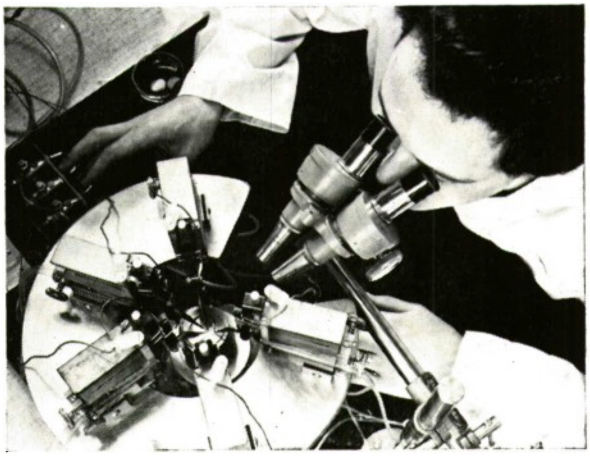
Following the work on materials in the Physics Group, a team in the Electronics Group is concerned with harnessing suitable specimens for use in lasers; this necessitates the development of efficient pump sources, the design of switching techniques and of the necessary optical systems. Similarly, effort is deployed in the further development of Gunn effect devices which may well lead to a solid state radar, albeit of low power.

Circuit and component development for the realisation of high power microwave generation is pursued with the aim of generating 15 MW peak pulses of 200 microseconds. Pulse compression and electric scanning are among associated R.F. techniques being studied in this Group.

Closely associated with this R.F. work is the work of the Radio Astronomy Division which is equipped with a Radio Interferometer comprising aerials of 82′ diameter separable up to a distance of half a mile, and with a fixed aerial installation of 140′ diameter. Experimental data concerning the upper atmosphere is being accumulated together with information on the size and structure of various extra galactic radio sources.

Industrial Systems Unit

Associated with the Physics and Electronics Department there has recently been formed a small Industrial Systems Unit whose function is to act as an interface between the work of the Establishment as a whole and Industry. Through this unit, relevant experts can be consulted on problems arising in industry and, in certain circumstances, tasks may be placed in appropriate areas of the Establishment on a repayment basis, subject always to the availability of effort from the main programme. In this way it is hoped that "spin off" from an essentially military programme can be made more readily available for civil purposes.



A multiprobe tester. The micro-integrated circuits on a single slice of semiconductor under test. Probes are positioned under a microscope and then covered onto the specimen under air pressure.

Relationship with University of Birmingham

During 1966 formal links with the University of Birmingham have been forged by appointing a small number of senior R.R.E. staff to honorary posts in the University—two at professorial level. A corresponding number of senior University staff have been appointed to honorary posts at R.R.E. In each case, these staff spend up to one day per week meeting their honorary commitments, some of the R.R.E. staff giving courses of lectures to post graduate students and taking part in the supervision of research projects. Correspondingly the University staff is made aware of critical problems facing the Establishment and of new techniques being developed.

THE PHYSIOLOGICAL SIGNIFICANCE OF ELECTRIFIED AIR

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SUMMARY

Physiological Effects. Nature of the Charged Particle. Respiratory Effects. Systemic Effects. Effect on the Blood and the Central Nervous System. Basic Problems.

The effect of weather, particularly on some subjects (who seem more sensitive than others) has presented a puzzle to physiologists for many years. Even in the eighteenth century there was speculation regarding the effects of electrified air.[1]

It was left to Dessauer[2] and his associates in Frankfort to carry the subject from speculation to a systematic study. Prof. Strasburger defined a physiological condition found in those who worked in Frankfort as "fatigue and inability to work." This condition disappeared when the patients moved to the hill country. He was able to reproduce the condition by causing the subjects to inhale air carrying a positive charge. Conversely the condition produced in this way (or by normal residence in Frankfort) could be relieved by inhaling air with a negative charge.

Extensive claims for the treatment encompassed such a wide range of complaints, from rheumatism to cardiac disorders, that it was regarded with some suspicion. In the U.S.A. Yaglou and Others [3], [4] were unable fully to confirm the results claimed in Germany. Nevertheless the subject was pursued with vigour largely under the patronage of the Wessix Electric Heater Company of San Francisco. The company sponsored a number of studies in 12 Universities and had the John Crerar Library make an extensive search of the literature. Their activities are well summarised in a paper by their President.[5]

A search of the extensive literature on the subject is, in some ways, disappointing. In the main, a great deal of research has been carried out by competent physiologists, who have carefully recorded the various parameters, which have seemed to them to be relevant. However, in most cases there is insufficient detail regarding the nature of the electrified air and conditions under which it was produced. Where details have been given, there is a lack of definitiveness due to the equipment at the time being insufficiently advanced to make reliable physical measurements. However, there is no doubt at all that some workers have shown that physiological effects *are* produced by inhaling air which carried either a positive or negative charge.

It is therefore worth while reviewing the present state of knowledge concerning "electrified air" and attempting to correlate this knowledge with the actual physiological results obtained.

Electrified Air

In 1752 Le Monnier showed that there is everywhere a permanent electrical potential difference between the air and the earth. In 1785 Coulomb investigated the electrical conductivity of the air. It is now known that a current of approximately 1000 amperes is flowing from the ionosphere to the entire surface of the earth. This current is equivalent to 2×10^{-16} amps/cm^2. The conductivity of the surface air is such, that the vertical potential gradient is 100 to 300 volts per metre, the air being positive with respect to the earth.

The conductivity of the air is due to the presence of large numbers of electrically charged particles known as "ions." These start life as molecules, which have gained or lost an electron and have subsequently gathered round themselves a further 10 or so molecules to form a cluster.

These ions are constantly being formed over the entire surface of the earth by the action of cosmic rays from outer space. Over land more than a half of the total originate in the respired air from the soil. These are produced from the emanations of traces of radioactive elements. Consequently at any

one time changes in barometric pressure and variations of wind, are potent factors in determining the rate of production of ions. The concentration is determined not only by the rate of production, but also by the rate of destruction. The latter process occurs in a number of ways. When two ions of opposite polarity collide, they are self annihilating. Ions also are lost by impaction on other particles in the air or on surfaces over which they are carried by air currents. This latter effect is of importance in forced ventilating systems, when the ion content (particularly the negative) may be reduced by up to 30 per cent by impaction on the walls of the ducting.[6] Where full air conditioning is in use, the ion content appears to be increased by the air being impelled over hot surfaces by a fan. Cooling by a water spray removes them altogether. The average concentration has been quoted by various authorities as lying between 50 and 200 per cc. The rarity of small ions may be realised when it is remembered that air contains 17×10^{18} molecules/cc. There is an overall daily and yearly variation beside wide differences in short intervals of time, from place to place and even in the same locality.

Owing to their small size, it is usual to describe them by another property, known as their mobility (K). This is the velocity with which they move in unit electric field (1 volt/cm). Their actual size is of the order 5 to 20Å and their mobilities lie between about 1·5 and 0·5 cms/sec/volt/cm in air—the negative ions having a slightly higher mobility than the positive.

Primarily the action of radiation is to cause an electron to be ejected from a molecule. Investigations by Laporte [7] show that no preference is shown in favour of any one constituent in the air. On the other hand, the ejected electron appears to attach itself more readily to neutral oxygen molecules rather than to nitrogen. The positive ions in the air may therefore be formed on a variety of chemical elements, while the negative ions are largely formed from oxygen.

Due to their movement in the earth's electric field the concentration of positive ions near the surface of the earth is somewhat greater than that of negative ions.

Ions may be generated artificially by radioactive emanations or X-rays. Additionally methods have been used based on ultraviolet light, high voltage corona, high frequency arcs, flames and incandescent alkalis or metals. These latter methods have the disadvantage of initiating chemical changes in the air. Among such changes the formation of ozone and oxides of nitrogen is to be expected. In the case of ultraviolet light, sulphur dioxide—an ever present contaminant in the air—is oxidized to sulphuric acid.

In addition to ions there is also present in the atmosphere a bewildering array of other small particles, which constitute nuclei for the formation of condensed water droplets as mists or fogs. For this reason these particulates have become known as Condensation Nuclei.

By impaction with the charged ions, these nuclei can take over the ionic charge. Unfortunately this has led to the terms "large ion" and "small ion." No confusion need arise, if it is remembered that a charged condensation nucleus, of the same dimensions as a "small ion," does not lose its identity if its charge is neutralised; whereas two genuine small ions of opposite polarity are self annihilating on impact and revert to the uncharged molecular state from which they are formed.

It is now evident that there is a constant series of electrical reactions (or interchanges) going on between five distinct components, namely small positive ions, small negative ions, neutral nuclei, positively charged nuclei and negatively charged nuclei under conditions of overall electrical balance. Owing to differences in the reaction rates, there is a surplus of negatively charged nuclei and a corresponding surplus of positive small ions. This process further increases the excess of positive small ions over that already existing due to the effect of the earth's electric field.

Condensation nuclei are produced in nature as saline particulates from ocean spray. Over land, dust storms, volcanoes, and forest fires add their quota.

Particulates are generated by human activity largely as the products of combustion and to a lesser extent by industrial activities. Suspended particulates which have been identified include:

Carbon	*Chlorides*
metal dusts	sulphates
tars	silicates
resins	fluorides
pollens	nitrates
fungi	oxides
bacteria	organic complexes
virus	

The smaller particles, which are too small to be seen by optical methods, vary from a few hundred to more than a hundred thousand per cc

depending on the degree of contamination. However, the weight of matter involved is extremely small. Concentrations of a few hundred per cc represent a mass of about $10^{-7}\mu$grm/M^3. The life of a small ion depends very much on the number of nuclei present. In relatively clean air, the life may be of the order of a few minutes, but in a heavy contamination, this is reduced to a few seconds.

Thus the balance between the electric charges carried by small and large ions is a very variable factor.

Physiological Effects

Natural forces, often not fully comprehended, produce effects which are felt by some people and animals sensitive to changes in the weather. Some insects and plants also react to these conditions. Noticeable in this connection are certain winds in various locations: the Chinook in Alaska, the Zonda in Argentine, the Solano in Spain, the Sirocco in Sicily and the Föhn in the Alps. The latter in particular has been studied and found to carry an overall positive electric charge. This Föhn wind causes a characteristic sickness and is said to be detectable in advance of its actual arrival.

A more obvious example of the disturbance of electric balance is that afforded by thunderstorms. The direction of the earth's field is reversed and the storm is frequently followed by a ground level excess of negative rather than positive small ions. The feeling of freshness and well being after the storm has passed is well known. The connection between this state of well being and an excess of negative ions can be compared with the feeling of oppressiveness preceding the storm, when positive ions are greatly in excess of negative.

It has been observed by many people that a rapidly rising temperature with a falling barometer induces a feeling of restlessness and irritability, whereas exactly the reverse reactions result from a falling temperature and rising barometer.

Caspari in 1902, Sokoloff 1903 and Steffens 1910 each drew attention to the apparent connection between ionised air and certain physiological conditions. These and other effects of a rather general nature led Dessauer to develop an artificial ion generator, which he and his associates employed, during the period between the wars, for the treatment of various disorders.

The device consisted of a pellet of magnesium oxide, heated by a coil of platinum wire and held suspended in a field of several thousand volts. The air passing over this heated element was cooled, before being delivered to the patient for inhalation. It was believed that this air contained hundreds of thousands of minute particles of magnesium oxide, each carrying an electric charge. It could be arranged that this charge would be either positive or negative. The size of particle was estimated from measurements of the mobility and the weight of solid material retained by the respiratory system derived from appropriate measurements.

Dessauer's greatest successes, in which about 80% of the cases some improvement resulted, were obtained with such complaints as: high blood pressure, bronchitis, asthma, rheumatism, arthritis, gout, neuritis, neuralgia, heart and arterial disorders. Subjective reactions to the inhalation of positive particles were fatigue, dizziness, headaches and nausea. The symptoms were accompanied by increased B.M.R. and blood pressure and increased rate of respiration. The inhalation of negatively charged particles had precisely the opposite effect, producing a feeling of exhilaration and an apparent improvement in health.

In 1930 following the earlier work in Germany, Yaglou [3] at the Harvard University School of Public Health, Boston, U.S.A. carried out a series of experiments on similar lines, but using particles believed to be of much higher mobility (that is much smaller) than those used by Dessauer. These experiments were related to changes of B.M.R., respiration rate and blood pressure. While the experiments were planned and carried out from a physiological point of view with meticulous care, there is some ambiguity regarding the characteristics of the ion generator used. It is admitted that in the earlier experiments the inhaled air contained traces of ozone.

The results of these experiments confirmed in part only the work of Dessauer. Tangible results appeared to be obtained chiefly from subjects with some physical disorder.

The subjective effects of inhaling air carrying positive and negative charges were confirmed only to a limited extent.

In 1932 Bierman [8] reported preliminary results of the use of a Dessauer apparatus at the Beth Israel Hospital, New York. Partial confirmation of the Dessauer results were obtained. The equipment had been in use for only six months and during this time, certainly some patients responded to the treatment for respiratory disorders. It is of interest to note that partial confirmation was obtained of Dessauer's treatment of arthritis. Negative charges resulted initially in painful reactions, with some swelling of the joints, followed by subsequent improvement in the condition.

In view of the recent revival in the belief that the affliction is the result of bacterial activity[9] an earlier reference may be significant.[10] This contribution considers the dissociation of virulent to less virulent organisms and *vice versa*. Among the

factors concerned in such transformations, chilling and ionised air are cited.

In 1935 Herrington[12] carried out further work using albino rats, employing what he first thought to be high mobility small ions. He concluded that exposure to either positive or negative air produced no significant difference in haemoglobin or weight as compared with a control group. In these experiments the " ions " (obtained from a corona point discharge at 15,000 volts) were subsequently found to consist of a whole spectrum of particulate sizes. A review of the contradictory results obtained in these experiments indicate that relevant factors have been omitted. In every case the pollutants in the air had not been considered and no effort had been made to remove them.

The Charged Particle

In 1952 Martin [13] at Stanford University investigated the nature of charged particles produced from thermionic ion sources and found these to be difficult to design and control. Moreover, considerable variations were caused by atmospheric pollution: where high voltage generators are used similar problems arise, since, with each type of ion source, chemical reactions could have been initiated. Apart from these drawbacks, the physical instrumentation available at the time, leaves open to doubt the accuracy of both particle count and mobility and therefore particle size.

The only conclusion which can be reached is that in certain concentrations, physiological effects result from the inhalation of certain particles of a certain size, carrying either a positive or a negative charge.

However, none of this work identifies the size of the effective particle. This is of considerable importance, since it would appear at first sight, that due to their relatively high mobility, the true (small) ions (if present) would be collected in the nasal cavities or at least in the trachea. Similarly large nuclei would not be expected to penetrate as far as the alveoli, being lost by impaction on the trachea or the upper bronchiole.[14] Although statistically overwhelming doses of either size might be expected to achieve penetratiton by sheer weight of numbers, in general it would be expected that particles of an intermediate size might well be found to be the operative agency.[1, 15, 16]

In the post-war period as a result of Martin's rejection of thermal ion sources as suitable for biological research, an improved ion generator was designed under the Wessix patronage. This consisted of a radioactive source situated in an electric field. The ion pairs produced were separated by the field and those of the unwanted polarity collected. However a similar type of ion generator appears to have been described by Verigo, A. B. in 1932.[17]

Respiratory Effects

The improved type of generator was used by Krueger and Smith[18] at the University of California (1956-59) to study the effects of small ions on cells and tissues. The work was associated with the upper respiratory system and in particular with the trachea. Rats, mice and rabbits were used as experimental subjects.

Initially fresh strips of rabbit trachea were exposed to massive doses of ions of either charge.[19] In the later work[20, 21, 22] living animals were anaesthetized, tracheotomized and examined under a dissecting microscope. In some experiments the animal was exposed to the action of ions prior to the operation and in others the ions impacted directly on the tracheal opening.

Any inhaled particles which escape being trapped in the nasal cavities are impacted on the mucus layer resting on the ciliated epithelium of the trachea and bronchi. Once collected in this way, they are transported in a spiral path by ciliary agitation up the respiratory tract to the epiglottis and either expectorated or swallowed. It is believed that the proteins in the mucus supply an inhibitor, which prevents the initial union of certain virus particles with the cells of the mucosa.

In the experiments carried out by Krueger and Smith, the ciliary flicker was found to be stimulated by the action of negative ions in the air and depressed by positive ions. Analogously the resultant mucus flow was reduced by positive ions and in some cases the volume decreased. The process was reversed by negative ions. The results obtained with the extirpated tracheal strip indicate that effects are due to direct contact between the charged particles and the cells of the respiratory tissue. Quantitative estimates based on minimal doses suggest a distribution of single charged particles on each cell.

The later experiments were concerned with the relationship between the effects produced and the nature of the inhaled gas. The table overleaf summarizes the results obtained.

Cigarette smoke alone produced a temporary lowering of the rate of ciliary beat which returned to normal, when the apparatus was flushed with clean air. On the other hand, the changes produced by ionised gases resulted in one or other bistable state above or below the normal.

In their reports the authors are unique in remarking that the effects may have been due in part to pollutants in the air or in the gases used.

Although the work was primarily concerned with the trachea, the authors recorded[20] changes in the respiratory rates of (resting) animals inhaling air containing an excess of ions of either polarity.

Systemic Effects

Working with golden hamsters, Worden[23] showed that exposure, during the post natal development period, to an atmosphere containing a preponderance of negative ions, exerted a stimulating effect on the growth and on the ultimate weight of certain organs. Exposure to positive ions showed no significant difference from a control group.

In the same series of experiments Worden[24, 25] showed that animals breathing air with an elevated negative/positive ion ratio showed an increase in blood pH and increased capacity for CO_2 uptake of the blood plasma. Corresponding changes in chloride were also noticed.

Few references to the extensive work carried out in U.S.S.R. are given in the Western Literature on the subject. Vasiliev[26] (Pavlov Institute of Physiology, Leningrad) has summarized and referenced some of this work which is presently relevant. This paper gives an account of experiments which show beyond doubt that the blood itself is affected by receipt of charged particles on the alveoli. The effects are shown to be twofold. Firstly there is a reflex reaction from the central nervous system, excited by pulmonary interoceptors and secondly an effect produced directly from the affected blood. Vasiliev quotes evidence for the former (Kunevitsh) depending on results of vagotomy and (Blagodatova) for the latter by sectioning and clamping of the exterior iliac artery. In each case the effects were observed by chronaximetry of the hind leg of a rabbit. Evidence of the reflex action was further quoted (Vasiliev and Latmanizora) in connection with war wounds, where the nerves in parts of the body were completely severed from the central nervous system. The direct humoral effect was most convincingly demonstrated (Skorabogatova) by crossed blood circulation. In this case the second animal responded to the inhalation of charged particles by the donor animal. Similarly (Grobstein and Kersanov) have shown improvement in cases of ozena, where the patient has received blood transfusion from a donor who had been exposed to the inhalation of negatively charged particles. Gadzala injected rabbits with diphtheria toxin to produce myocarditis. Those exposed to negatively charged air survived for 20 days, the control group for eight days, and those exposed to positively charged air for only two days. It is therefore not without interest to attempt to trace the sequence of events in more detail.

Blood Effects

Venous blood is returned to the lung laden with carbon dioxide originating from the oxidation of carbohydrates in the tissues. The CO_2 is carried partly as solute in the plasma and partly as bicarbonate ions. In the lung it is expelled from the blood, due to its greater partial pressure, and its release results in a slight increase in pH value of the blood (about 0·03 around a figure of 7·4). At the same time molecular oxygen is absorbed through the alveolar membrane and leaves the lung with the arterial blood, in which it is stored, partly in solution, but chiefly in loose association with the haem in the red cells.

Normally if additional CO_2 is added to the inhaled air, the respiration rate is increased in such a way that the partial pressure of CO_2 in the arterial blood leaving the lung is almost unchanged. This increased rate is controlled by "chemostats", which respond to the concentration of CO_2 in the blood rather than to the oxygen content.

Conversely hyperventilation discharges an excess of CO_2 from the blood. This results in a condition of Apnea in which slow breathing is interrupted by pauses.

These two conditions are exactly represented by chart recordings, resulting from inhalation of air charged positively or negatively respectively.[27]

It is therefore reasonable to suppose that particles with a positive charge to some extent inhibit the normal discharge of CO_2 from the blood, while particles with a negative charge stimulate the process. In the latter case the arterial blood will have a slight deficiency of CO_2 and have a raised pH value as found by Worden and others. In this condition it would also have the ability to take up more CO_2 from the tissues, as was noted also by Worden.

The oxygen/carbon dioxide relation in blood is such that the loss of CO_2 assists the absorption of oxygen and *vice versa*. It follows therefore that the arrival in the lung of particles with a positive charge has two effects, namely: to cause both a deficiency of oxygen and also an excess of carbon dioxide in the arterial blood. In a more acute state, the former results in headache, lassitude, mental depression and irritability, while the latter produces anaesthesia and ultimately narcosis.

It is difficult to ignore the correlation between conditions resulting, on the one hand from artificial interferences with normal breathing, and on the other from inhaling air containing charged particles.

In the latter case the epithelium appears to act as an ion exchange membrane where the effect is concerned with bicarbonate ion, rather than with gaseous diffusion controlled by differential partial pressure.

No Effects Observed			*Effects Observed*	
$+ve$	$-ve$	*No ion-isation*	$+ve$	$-ve$
N_2	N_2	N_2	Air	Air
O_2	CO_2	O_2	CO_2	O_2
Air with CO_2 removed		CO_2	Cigarette smoke	Cigarette smoke

The Problem

This conclusion again raises the question as to the nature and size of the particle, which carries the charge through the upper respiratory passages to the alveoli in the deep lung.

There is also the problem of how to account for sufficient positive or negative charge to produce the observed effects in the absence of artificial generators.

In a relatively clean atmosphere, where the pollution particulates do not greatly outnumber the small ions, the former carry an excess negative charge and the latter an excess positive charge. The excess of positive small ions is further emphasised by the action of the earth's field and the greater impaction on surfaces of the small negative ion due to its greater mobility. In heavier concentrations of pollution it is to be expected that small ions would attach themselves to the larger particulates almost as soon as they were formed[28].

Whatever the answer may be found to be, there is little doubt that at least certain individuals are affected by the state of electrical charge in the air they breathe. In this connection it can be noted that dramatic effects were observed and treated in Frankfort, yet no reactions were obtained in Boston. In the former, the subjects experienced great privations during their post-natal development in the First World War period, while the latter subjects almost certainly grew up under relatively privileged conditions. In the former the effects were found in a grossly contaminated atmosphere and significantly disappeared, either by treatment or by residence in the comparative cleanliness of the hill country.

The fact that these subjective effects persist in a polluted atmosphere is evidence that the human system does not appear capable of fully adjusting itself to the adverse conditions. At the same time the evidence points toward an oxygen deficiency and an excess of CO_2 in the blood. Under these conditions, the chemostat system should react by increasing the respiration rate thus increasing the alveolar ventilation, but if this occurs, it does not appear to relieve the situation.

It may be significant to note the observation of Worden[24] to the effect that the increased CO_2 uptake is accompanied by equivalent chloride changes, thus implicating the red cells. Of greater significance is the fact that the results were obtained in the co-existence of polluted air.

In the Krueger Smith Experiments[20] using various gases, doses in excess of the minimal produced the effect *more rapidly* when cigarette smoke was added. The effect was *no greater*, since it would have been obtained even without the smoke aerosol. It would have been of value to know if the aerosol would have affected the result with doses *below* the minimal, thus linking up with the known synergistic action of inert aerosols on toxic gases.[29, 30]

A further point to note in this series of experiments on the trachea, is the existence of the two bistable states existing on either side of the normal. No corresponding observations were made in the work of other investigators concerned with the effects on the lung. If such bistable conditions exist here also, as a result of electrical charges, it is possible that the chemostat mechanisms in the medulla body are not capable of normalising the situation and therefore remain in an excited state.

That stresses are set up in the central nervous system is evidenced by the work of Silverman and Kornbleuh[31] who have shown that the frequency of the alpha rhythm is depressed by inhaling negatively charged particles.

If the effects are due to a condition to which the chemostats cannot fully compensate, could this have arisen from the inhalation of some constituent in polluted air ?

Such a condition could result from the migration of atmospheric acid radicles through the alveolar membrane under the influence of electric charges. The introduction of a mineral acid would not be expected to result in an increased respiration rate, commensurate with a depressed pH value, since it has been shown that the chemostats react primarily to the bicarbonate ion and much less to those of mineral acids. A 24-hour, seven-day-a-week inhalation of polluted air in such a case, would result in a circulatory system always slightly deficient in oxygen and carrying at least traces of foreign ion.

Until the experiments are repeated under more vigorous conditions where the chemical constituents of the inhaled air are controlled and the ionic content accurately assessed, the answers to these questions must be a matter of conjecture.

The fact remains that at least some people living in urban areas and breathing polluted urban air for 24 hours a day, instinctively attempt to escape to the seaside or the country to find cleaner air. That they absorb a greater quantity of pollution (including lead) on the way, does not prevent this instinctive behaviour.

The hypothetical connection between cigarette smoking and lung cancer has to a large extent resulted in a sense of false security regarding the factual dangers of polluted air. Respiratory diseases are accepted as a normal commitment of urban life.

It is however a disturbing thought that the increase in cardiac diseases might be associated with the inhalation of acid pollution, especially since the post mortems showed a strong connection in the case of the 1952 smog mortalities. It is even more disturbing to wonder how far the rise in mental disorders—particularly in urban areas—may be related to the effects of air pollution on the central nervous system.

There are pointers in both directions. Gilfillan[32] has traced the gradual disintegration of the Roman Empire to the protracted poisoning from the extensive use of lead.

It would be sad indeed if some future historian were able to trace a connection between the passing of European Civilisation and the polluted air which it created and breathed.

Quién Sabe?

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OXY-HELIUM DIVING

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There have been in the past century a number of underwater activities which have necessitated men exposing themselves to raised pressures of air. In recent years these activities have increased both in number and in the demands placed upon the men. It is now commercially and militarily desirable that men should be able to work, and if necessary, live for prolonged periods on any part of the continental shelf. This comparatively new field of activity demands a great deal of study of the physics and physiology involved in order to proceed with confidence. It is hoped to show in this paper some of the problems and the first steps that are being taken to surmount them. When contemplating the possibility of life at pressures in excess of 10 atmospheres absolute, equivalent to a sea depth of 300 ft., one of the first essentials is to decide the nature of the gas to be breathed. There must be a sufficient pressure of oxygen to support life adequately, but not such a value that will cause oxygen poisoning effects. It is generally accepted that more than 0·18 atmospheres partial pressure of oxygen is essential for full efficiency but that for prolonged breathing no more than 0·6 atmospheres is permissible. For most normal exposures to pressure which have a duration of 30 minutes or less it is generally agreed that the upper oxygen limit may be as high as 2·0 atmospheres.

Having decided upon the oxygen partial pressure it is now necessary to rely upon some suitable inert gas for the remaining pressure. Above 10 atmospheres the only practicable gas to use is helium. Helium is light and relatively easy to breathe at great pressures, and also it exerts the least narcotic effect of all the other possible inert gases. Xenon is narcotic at atmospheric pressure and has been used as an anaesthetic agent in deep surgical procedures. No systematic work has been performed on krypton breathing but it has been qualitatively assessed as less narcotic than xenon. Argon becomes too heavily narcotic for most diving purposes at pressures around 4 atmospheres. Helium does not show any appreciable narcotic effect.

After a man has been exposed to a high pressure helium atmosphere the body tissues have considerable volumes of this gas dissolved in them. The safe decompression of such a man may take several hours or several days depending upon the depth-time combination of the exposure. This entails men living in pressure chambers and breathing synthetic atmospheres for prolonged periods. Some form of air conditioning is essential both for comfort and to avoid complications during the decompression. The two main gas variables are the oxygen and carbon dioxide content. On no account must the carbon dioxide content exceed a partial pressure greater than 1% of an atmosphere. To this end some form of monitoring system has to be devised. If samples are taken from the pressure chamber and reduced to atmospheric pressure then at 20 atmospheres pressure inside the chamber the partial pressure of carbon dioxide available for analysis is reduced by a factor of 20. Effectively this means that with 1% inside the chamber there is only 0·05% outside for analysis. Detecting changes in such small percentages is very troublesome and this has been abandoned in favour of doing estimations at the pressure of the chamber. Here the difficulty is finding apparatus which will function reliably under high ambient pressures. Eventually the method which proved most effective was to break evacuated capsules containing known amounts of barium hydroxide and phenol-phthalein indicator into a known volume of the chamber air. This simple method proved reliable and accurate and

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fortunately the delay in carrying out an analysis was of no practical importance because there was only a slow rate of change of carbon dioxide.

Oxygen concentrations were fortunately much easier to follow and this was performed with a conventional paramagnetic analyser from samples allowed to expand to atmospheric pressure. The relative humidity inside was nearly always 100%. The only exception to this occurred for a few minutes after the men were first compressed with pure dry gas from the high pressure storage cylinders. No attempt was made to reduce the humidity inside the chamber as this gave good protection from any possibility of fire caused by static electricity generated in the brushed nylon suits which they wore. The remainder of the atmospheric contaminants were the usual ones from body odours. These latter are most effectively dealt with by two methods. Firstly the use of a multi-compartment pressure chamber which has separate toilets, eating and resting compartments, and secondly by a periodic complete change of the atmosphere. The latter is accomplished by confining the men for a short while to a small pressurised compartment whilst the remainder of the pressure chamber is reduced to atmospheric pressure. After rapid cleaning out operations have ceased the chamber is then re-pressurised and the men released from their temporary refuge.

The diving chamber descends into the sea at a rate of 100 ft. per minute. Before commencing descent the chamber has all the air replaced by 20% oxygen 80% helium gas. This is accomplished by displacing air downwards, the much lighter helium gas is put in at the top and the air is pushed out of the bottom drain valve. A balloon filled with helium gas rests on the interface between the air and the helium displacing it. This gives a very good simple indication of the completeness of the process and subsequent chromatographic analysis has not revealed more than 2% nitrogen left in the chamber. After this flushing out process the divers are lowered to depth in a submersible chamber. The pressure rises rapidly and water enters the bottom opening as the steel door for this is kept open. More gas is supplied from the surface ship *via* pressure hose in order to keep the water level in the lower part of the submersible chamber. When the man reaches his maximum depth he will undoubtedly be feeling unsettled especially if the depth is 600 ft. or over. There develops a distinct shaking of the hands and forearms which prevents the diver making fine movements. On the test applied at this laboratory it can be seen that it is difficult for most men to pick up small objects and handle them accurately. Tests on ability to do mental tasks also show a noticeable deterioration. This impairment of performance begins to lessen as the time at depth continues, and after about one hour at 600 ft. most men are back to normal. This return to normal performance is maintained over the next few hours. The maximum breathing capacity of men at this depth has fallen considerably but nevertheless it is possible to perform extremely hard and continuous physical work without any apparent ill effects.

As a result of the stay at high pressure the tissues of the body have acquired large volumes of dissolved gas. If the exposure has been of only a few minutes then well vascularised tissues will be nearly saturated with gas whereas those such as cartilage, fat *etc.* with poor blood supplies will only contain very small quantities. Decompressing in such complex situations without causing the formation of bubbles and hence decompression sickness has proven to be a matter of trial and error to attempt to define the boundary conditions of the problem.

Ratio Principle of Haldane

Goats were first used to assess the following hypothesis. After a saturation exposure to pressure P_1 it is possible to ascend rapidly and safely to a pressure P_2 and that there is some simple relationship between P_1 and P_2 such that

$$\frac{P_1}{P_2} = r \text{ (constant) or } P_1 - P_2 = K \text{ (constant).}$$

In the first instance this was tried on air, using a six hour exposure at P_1 followed by ascent in $2\frac{1}{2}$ minutes to P_2.

The pressure ratio which just gave a mild attack of the bends is obtained for each goat for a representative set of values of P_1. These threshold ratios are plotted versus the initial pressure of exposure in Fig. 1. As may be seen the ratio

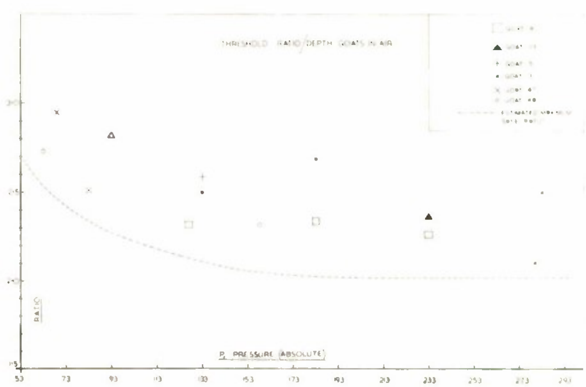

FIG. 1.

diminishes with increase of pressure and this decrease is most marked in the first 140 ft. (absolute) pressure. From 149 ft. to 230 ft. absolute the ratio is nearly constant and these observations agree qualitatively with the power function curves expressing the relationship between pressures and ratio used in the calculation of the U.S.N. air decompression tables. It is of interest to note that some of the results were obtained by changing from greater than atmospheric pressure to sub-atmospheric pressure. Similar threshold values are being obtained by changing from greater than atmospheric pressure to sub-atmospheric pressure. Similar threshold values are being obtained using helium-oxygen as the breathing medium. For men it has been shown that four hours at 300 ft. may be followed by rapid ascent to 170 ft. without any ill offects in a group of 12 men. In Table 1 is plotted the threshold ratios for saturation or near saturation dives on goats and men. On all these occasions a relatively mild attack of decompression sickness has been taken as indicating the threshold.

TABLE I.

Variation of Threshold Ratio Following a Long Exposure to Oxy-Helium Gas

Pressure (Gauge)		*Ratio for Goats*	*Ratio for Men*
Ft. (Sea Water)	P.S.I.		
45	17·8	–	2·67
66	29·4	3·0	–
350	155·9	2·09	–
600	267·2	2·0	–
800	356·3	–	1·59

The cut-back in the critical ratio on the goats breathing helium has the same features as on air. In the pressure range of 350 ft. to 600 ft. there seems to be a definite but relatively small change in the critical ratio, whereas from 350 ft. to 66 ft. there is a large change. With men the critical data are not well established but it has been shown that in addition to the data in Table 1 a two-hour exposure at 500 ft. may safely be followed by a rapid ascent to 290 ft. (ratio 1·65) and using 12 men, four hours at 300 ft. may safely be followed by rapid ascent to 170 ft. (1·64 ratio). The rule has now been reached that for dives at depths greater than 250 ft. a 1·6 ratio or a drop in pressure of 200 ft., which ever involves the least pressure change, is quite safe to establish the pressure value of the first stop following dives to depths as great as 800 ft. for bottom times as long as four hours.

The goats were next used to establish the form of safe decompression schedules using only oxy-helium as the breathing medium. Fig. 2 shows a series of attempts to reach 165 ft. following a dive of 50 minutes at 600 ft. by a single stage at 300 ft. A duration at 300 ft. of 30 minutes was grossly inadequate to follow ascent to 165 ft. *i.e.* a ratio change of only 1·68 following a first ratio change of 1·9. A one hour stay at 300 ft. followed by an

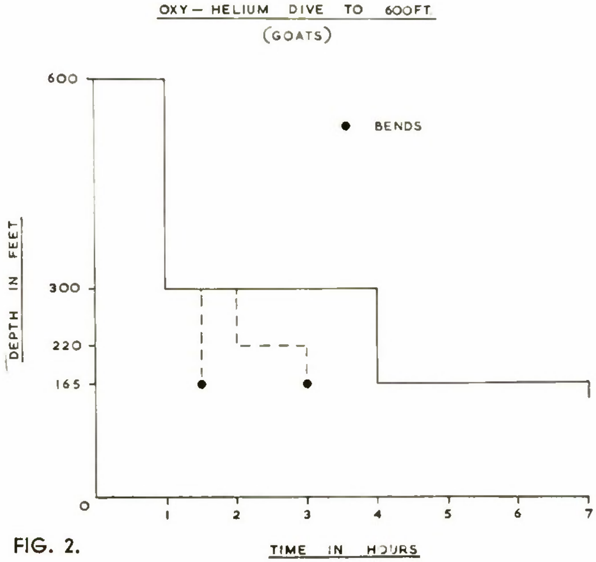

FIG. 2.

intermediate stay of one hour at 220 ft. was still inadequate to permit safe ascent to 165 ft. Eventually a three hour stay at 300 ft. was found necessary to ensure trouble-free ascent to 165 ft. This served to emphasize findings similar to those found on air (Hempleman). The rate of loss of the risk of decompression sickness is not the same as the rate of acquisition of this risk. No difference could be detected in the decompression requirements of a dive of 50 minutes' duration and one of six hours. However when decompressing from such a dive a 50 minutes' duration at a stage is certainly not equally as effective at three hours. This irreversibility was seen during the subsequent three hours stops from 165 ft. to the surface. Pressure changes corresponding to a ratio of 1·3 were performed after a stage (stop) duration of three hours. This procedure met with complete success, but an attempt to repeat a 1·6 ratio following a three hours stay met with failure at the 60 ft. level. Such a finding demonstrates that even after three hours the tissues of the animal are nowhere near returned to normal, otherwise immediate return to atmospheric pressure would have been possible, giving a ratio change of 2·82. To achieve such a ratio change would clearly require many hours in excess of the three already tested. Viewing this as a reflection of tissue half-times it is possible to state that the half-times necessary to explain the tissue de-saturation data

in the decompression procedures are many times greater than the tissue half-times necessary to explain the saturation data. At this juncture it may be concluded that the use of large and sudden pressure changes in the stage method of decompression creates a dangerous situation in the tissues closely approximating to an attack of decompression sickness. The possibility exists that if smaller pressure changes were made then there would be a more rapid pressure-time course back to atmospheric pressure. This hypothesis was

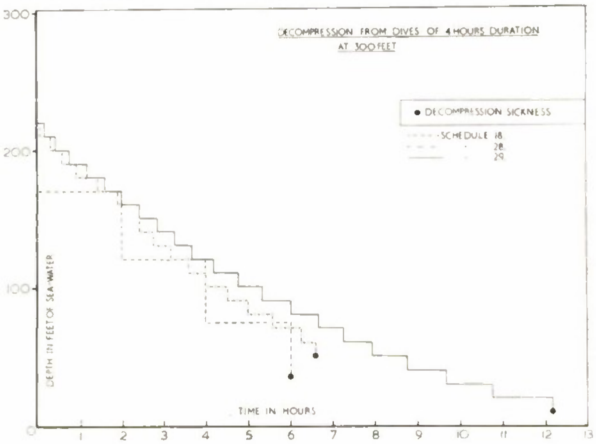

FIG. 3.

tested a number of times on male human volunteers. Three representative sets of results are plotted in Fig. 3. An exposure of four hours' duration at 300 ft. pressure, breathing 10% oxygen 90% helium, and using unacclimatised exercising subjects, was followed in many cases by rapid ascent to 170 ft. with a period of two hours at this stage, and then rapid ascent to 120 ft. with a two hours' pause here. These long duration stops and large pressure drops can give a successful but lengthy decompression. Several attempts were made to drop the pressure rapidly only to 220 ft. and then follow in 10 ft. stages a relatively smooth decompression back to atmospheric pressure. This procedure clearly did not offer any great advantages in time. In order to avoid the bends it was necessary to-reshape the pressure-time course so that the total decompression time was not significantly different from the previous technique of adopting long duration stops followed by relatively large pressure changes. There is a third possibility for achieving a shorter decompression schedule. If it is possible to ascend rapidly to a stop value which would normally be expected to give a severe attack of the bends, then there is a latent period for the appearance of decompression sickness. The situation is entirely analogous to the man at atmospheric pressure in the first phase of a surface decompression dive. In this latent period it is possible to change the composition of the breathing mixture and attempt to avert the impending attack. Several successful dives of this nature were attempted where the breathing medium was changed from oxy-helium to air during the latent period, with the result that very short decompression times were successfully accomplished by a team of men both in the chamber and in the sea. Unfortunately it was found that when this procedure failed to work there was a very serious form of decompression sickness, and it was decided not to pursue this technique any further.

As well as finding that the decompression pressure-time course when breathing oxy-helium was quite flexible, there were a number of puzzling observations on the rôle of oxygen in diving. A dive of 16 minutes to 400 ft. breathing 10% oxygen, 90% helium gave two bends out of four attempts. When exactly the same dive, with the same decompression schedule was attempted breathing 13% oxygen, 87% helium then 10 trouble-free dives in the sea were performed. This confirmed the generally held view that oxygen-rich mixtures were advantageous to the diver, and agrees with previous work (Hempleman). However when oxygen rich mixtures were used in the later stages of many of the prolonged decompressions necessary from deep prolonged dives they did not give any noticeable benefit. This is borne out by the following observations. The schedule to be discussed is given below in Table 2.

TABLE 2

Depth	300	170	120	80	55	35	20	10
Time	4	3	3	3	3	3	3	1

Here the divers breath 10% oxygen, 90% helium at 300 ft. and 20% oxygen, 80% helium from 170 ft. to 80 ft., 60% oxygen, 40% helium from 55 ft. to 20 ft. and oxygen for one hour at 10 ft. This is a reasonably successful procedure on unacclimatised men and in fact gave two transient niggles at the first attempt by a pair of divers. In one man these transient attacks were noted from 55 feet to the surface, re-occurring at every pressure stage and disappearing in a minute or two. The other diver had similar affects but only on reaching atmospheric pressure. This was considered marginally safe, but in order to test whether oxygen made any really worthwhile contribution it was decided to breathe 20% oxygen, 80% helium from 170 ft. to 20 ft. and then to change to 40% oxygen, 60% helium at 20 ft. and

10 ft. No oxygen breathing was performed. This in theory should render the schedule alarmingly unsafe if oxygen has the rôle usually attributed to it. In fact six men attempted this dive and only one man had a transient niggle during the decompression. Far from being rendered more unsafe it was the impression that the dive was made safer. Following these dives, a number of dives of one hour duration at 300 ft. were also tried using schedules involving oxygen breathing from 50 ft. to the surface. In order to avoid bends in the last 50 ft. of the schedule it became clear that it would be necessary to breathe pure oxygen for times in excess of two hours and such prolonged breathing of oxygen was considered undesirable. A change was made to oxy-helium mixtures without any noticeable increase in the time requirements for a safe ascent. It is now considered that breathing of oxygen during the decompression may cause vasoconstriction giving a lowered inert gas elimination rate and that this effect can offset any benefit derived from the lack of inert gas pressure in the arterial blood. Breathing oxygen or oxygen rich mixtures during the time on the bottom, or even just prior to the dive, is of course very beneficial for exactly the same reasons operating in reverse.

The main principles are now established for calculating schedules.

(1) The body tissues effectively saturate in four hours.

(2) It is possible to extend the general idcas of calculating air tables *i.e.* stage decompression, ratio cut back.

(3) There is an irreversibility in the uptake and elimination of the gas responsible for decompression sickness.

(4) Oxygen and oxygen-rich mixtures do not confer the benefit expected when breathed during the decompression.

In addition to these general principles there are several necessary controls on the diver and his environment.

(1) It is necessary to test schedules on either only acclimatised men or only completely unacclimatised men.

(2) Hard work whilst on the bottom is essential to give a severe test to a schedule.

(3) Work during the decompression must be reduced to the minimum.

(4) Pressure measurements at sea can never follow the same pattern as in the laboratory. This is due to wave motion and sea swell as well as the fact that in any real situation the diver alters his position in the water from time to time. At depths of 600 feet for instance a variation of 15 feet may well be encountered.

(5) During the dive and decompression the diver must keep warm. In laboratory experiments the temperature ranged between 80°F and 90°F, whereas at sea in our recent trials the temperatures varied between 55°F and 60°F. The divers were very cold during the dive and for the first part of the decompression, and this was thought to be influencing the outcome of the decompression.

(6) Atmosphere control must ensure accurate breathing mixtures, and carbon dioxide must not rise above a partial pressure of 1% of 1 atmosphere.

(7) A schedule is not considered successful unless 10 trouble free divcs are performed by 10 different divers.

Helium diving at sea has always produced more decompression sickness than in the laboratory. At present the effects of cold and raised carbon dioxide pressures are being tested on small animals.

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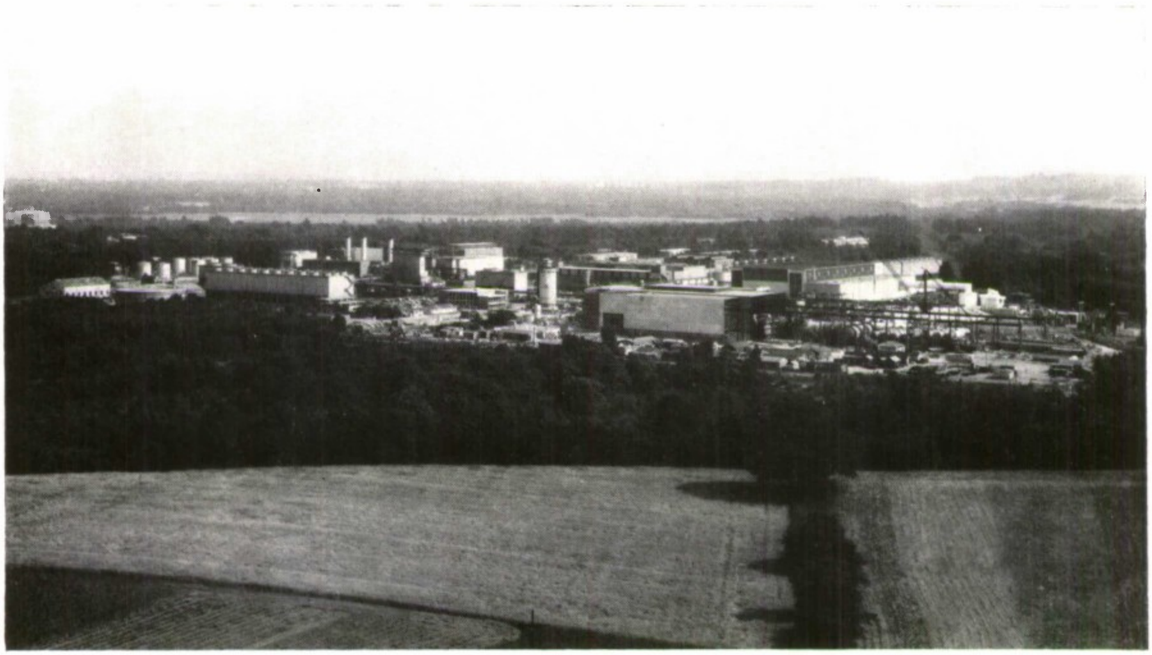
THE NATIONAL GAS TURBINE ESTABLISHMENT



Introduction

The National Gas Turbine Establishment at Pyestock in Hampshire is the Government centre in the United Kingdom for research into the problems of gas turbine engines and related systems.

A previous article by C. E. Moss (*J.R.N.S.S.*, Vol. 4, No. 3, May 1949) traced the origins of the Establishment back to the original gas turbine research undertaken by the late Dr. A. A. Griffiths at the Royal Aircraft Establishment and by Air Commodore Sir Frank Whittle at Power Jets Ltd.

In 1949, there were two branches of the Establishment, one at Pyestock, and the other at Whetstone in Leicestershire, but it was envisaged that they would be brought together on a centralised site at some future date. The site selected was Pyestock and the movement of equipment and personnel from Whetstone was finally completed in 1955. In the intervening years since 1949 the Pyestock site has been expanded and developed, particularly during the last decade or so with the installation of large scale plant for full scale environmental testing of aircraft powerplants.

Because of its original mandate for research and development of gas turbines for land, sea and air uses and its contact with a wide range of industry, the N.G.T.E. today is well-placed to make a major contribution to the technological progress necessary for National survival. Advance evidence of this exists in the contribution already made by the Naval Marine Wing, coupled with the increased use of aircraft-type gas turbines for the propulsion of Navy ships and other purposes.

In the following sections, some facets of the Establishment are presented, to provide as complete a picture as possible in the space available.

The Aero-engine Research Programme

Some two-thirds of the professional staff currently in post are engaged on the Establishment's research programme, with additional responsibilities, delegated from headquarters, for the management and monitoring of the bulk of Government-sponsored research in the aero-engine industry.

The major part of the Establishment's "in-house" programme (and for that matter the extra-mural programme), is directed towards applications which are clearly defined and expected to be in operational service in the short term, the remainder being work of general value. A small amount of effort is, naturally, devoted to longer term considerations. Although most of the programme is self-contained, there are various interfaces with other interests where the work concerns, for example, air intakes, propelling nozzles, general installation matters and, of course, materials; close liaison on these aspects is maintained with other Government Establishments and companies concerned.

The programme is organised by Research Fields as follows:—

(a) *Assessment of Powerplant Performance and Application*
This research constitutes a small, highly directed, continuous quest for ways of improving gas turbines and jet propulsion systems in respect of overall performance and cost effectiveness. The bulk of the work is on engine design studies, mission studies and engine selection, undertaken largely in conjunction with the airframe specialists and concerned almost exclusively with investigation of proposals to meet user requirements.

(b) *The Interaction of Propulsive and Lifting Flow Systems*
Here the work covers various aspects of the hot gas re-circulation, ground erosion and débris ingestion problems in V/STOL systems such as the Hawker Siddeley 'Kestrel'. The main effort is engaged on the N.G.T.E. technique for the exploitation of aerodynamic circulation control, with particular reference to helicopters, for which the circulation-controlled rigid rotor offers operational and performance advantages, together with a prospect of reduced maintenance and improved reliability. There is also a lively interest in an earlier N.G.T.E. proposal for high speed, stoppable rotor, V/STOL aircraft conforming to such low noise standards that the same basic aircraft could be conceived in a civil as well as a military rôle (see Fig. 1).

(c) *Powerplant Operation and Control*
Work on powerplant items such as air intakes, propelling nozzles, control systems and general installation and operational problems, forms an important section of the programme. The increases in versatility and in the variety of operations required of modern aircraft have accentuated the problems of optimising powerplant performance and minimising drag. The successful application of high by-pass ratio engines is critically dependent upon solving the resulting installation problems. Increased powerplant complexity and the continuing drive to improve engine handling have maintained emphasis on control systems research. Attention is currently focused on the possibility of applying digital computers to engine control, and on the use of fluidic logic in supporting sub-systems.

(d) *Engine Rotor Systems—Fans, Compressors, Turbines*
The high proportion of expenditure in this field, about one quarter of the total, reflects the continuing effort which is necessary to uprate the performance of turbo-machinery.

FIG. 1. A glimpse of the future ?—Low noise level vertical take-off and descent combined with high speed cruise using N.G.T.E. circulation-controlled stoppable rotors.

The work is aimed at reduction of component size, weight and cost, improved efficiency, and flow stability in conjunction with aircraft intakes, and makes full use of advanced digital computers. Research is also in progress on a single stage centrifugal compressor of some $6\frac{1}{2}:1$ pressure ratio for small gas turbines, as a contribution to good part load fuel consumption is to be obtained by its use in association with

This article, presented by the Director, R. H. Weir, C.B., B.Sc., C.Eng., F.R.Ae.S., is based on individual contributions by I. M. Davidson, B.Sc., C.Eng., A.F.R.Ae.S., Deputy Director/Research and Development; W. G. Fletcher, M.Eng., C.Eng., M.I.Mech.E., F.I.E.E., Deputy Director/Engineering; Cdr. J. C. Hallifax, R.N., A.M.I.Mech.E., O. in C., Naval Marine Wing, and P. F. Ashwood, B.Sc.(Eng.), C.Eng., D.I.C., M.I.Mech.E., A.F.R.Ae.S., Head/Engine Test Department.

a rotary regenerative heat exchanger and a variable geometry free power turbine. Such engines have considerable potential for helicopters, light aircraft, marine craft and surface vehicles.

(e) *Combustion Systems and Associated Chemical and Physical Phenomena*
The combustion programme contains a base load of work on fuel injection, ignition, mixing processes, film cooling and heat transfer, under conditions closely simulating those obtaining in practical combustion chambers. The increasing range of duties for the aero-engine has re-emphasised the fact that combustion chamber design is a compromise between the conflicting requirements of various operational conditions. Experiments are aimed at a burning zone operating near stoichiometric fuel/air ratio coupled with variable geometry to control the division of airflow within the chamber over a wide range of overall fuel/air ratio. Because of the method of their construction, combustion chambers are more amenable to change during development than, say, a compressor, in consequence the results of the research can not only be absorbed rapidly into engine development projects, but can, in some instances, be fitted retrospectively to service engines during overhaul.

(f) *Mechanical Engineering and the Use of Materials*
The bulk of the work in this field is extramural, the N.G.T.E. contribution being usually model scale, in contrast to the full-scale work undertaken by the firms. A good example of this is the N.G.T.E. small scale disc research, which forms an essential and relatively inexpensive adjunct to the full-scale work done in industry. The N.G.T.E. materials research programme is concerned mainly with high temperature applications and it includes the evaluation of possible new turbine materials, such as niobium, together with the development of protective coatings for easily oxidised alloys. Research is also proceeding on the wire reinforcement of nickel based alloys and on the impregnation of carbon fibres with aluminium. Another class of study concerns the erosion of gas turbine blading during the operation of helicopter engines in desert regions, and the resistance of high temperature materials to sea-salt corrosion is under investigation in the laboratory as well as in the Naval Marine Wing. Considerable interest attaches to the use of reinforced plastics for engine components, in particular for the fan blades of high by-pass ratio engines and for the low temperature components of lift engines.

(g) *Noise*
The Government-sponsored engine noise research programme is closely co-ordinated by N.G.T.E., which itself undertakes about one-quarter of the work. For some years now much of the programme has been concerned with turbo-machinery noise, including helicopter rotors—in preparation for the coming breed of big fan engines. However, the problems of jet noise are still far from complete understanding and there are also significant items in the subjects of noise propagation and perception. To make possible the free-field environmental testing of full-scale fans and compressors, a national turbo-machinery noise laboratory is now under construction at Ansty near Coventry for use by the various organisations as appropriate.

Full-Scale Engine Environmental Testing

(a) *The Engine Test Facility*

The Engine Test Facility at Pyestock enables a complete simulation to be made of the flight conditions encountered by an engine in an aircraft. Steady-state and transient operating conditions can be represented and special tests can be undertaken, for example trials under altitude icing conditions to examine the effectiveness of measures to prevent the build-up of ice on the intake or engine. The Facility (see general view) consists of a centralized pressure air supply/exhaust extraction plant, four cylindrical test cells with their control rooms and a data acquisition and processing centre. There is in addition a normally aspirated test bed (Glen Test House) used

FIG. 3. Compressor/exhauster sets in the Air House.

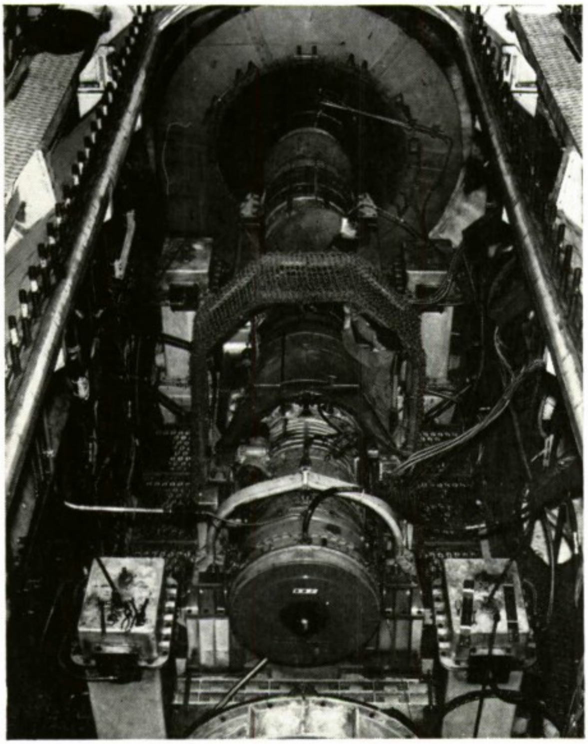


FIG. 4. An Olympus engine being installed for test in Cell 3.

primarily for research and development tests and for calibrating engines before installation in the altitude cells.

Two main types of test arrangement, " free-jet " and " connected ", are employed. In a free-jet test a stream of air moving at the aircraft flight speed is produced in a manner analogous to that of a conventional wind tunnel; the engine and its intake can thus be tested together under conditions encountered in free flight. In a connected test air is piped directly to the engine compressor at the same pressure and temperature conditions as would be provided at the compressor face by the intake in flight.

Both types of test require compressors to provide large quantities of compressed air and exhausters to pump even larger quantities of exhaust gases away from the altitude pressure level simulated in the test cell. These requirements are met by machinery located in the Air House (see Fig. 3). There are eight large compressor/exhauster units, each of which can be run either as a compressor or as an exhauster and the total installed electrical power is about 350,000 h.p.

Air is taken from atmosphere through driers before being compressed by the compressor/exhauster units to either three or nine atmospheres pressure depending on the test requirements. It is then further processed to adjust its temperature before being fed into the test cell. For example, in Cell 3 some of the pressure air can be expanded in a turbine and its temperature reduced to $-80°C$. This cold air can then be mixed with dry atmospheric air or with air which has passed through other of the compressor/exhauster units to achieve a wide range of temperature control at inlet to the engine.

Having passed through the engine the exhaust is cooled and pumped from the cell to atmosphere. In Cells 1 and 2 this extraction is by means of air-driven ejectors, but in Cells 3 and 4 it is obtained by using the compressor/exhauster units. The air supply system is thus capable of simulating both the true flight conditions corresponding to the pressure and temperature at the compressor face, as well as the lower pressure conditions around the exhaust system corresponding to the altitude at which the aircraft is flying.

Cells 1 and 2 are 12 ft. diameter and they have been in use for eight years. Cell 3 is a 20 ft. diameter cell which has been in operation for five years and Fig. 4 shows an Olympus engine being prepared for test in this cell; the lid of the cell has been removed to allow the engine to be lowered in from above. Cell 4, shown in Fig. 5, is a large free-jet cell which first came into routine operation during 1966.

Cell 1 is used for free-jet testing of ramjets and for model intake research work at full scale Reynolds number. Normally the free-stream approach Mach number is fixed during a test but incidence can be varied while running. A range of supersonic nozzles enables tests to be undertaken between Mach 2·0 and 3·0, and using a

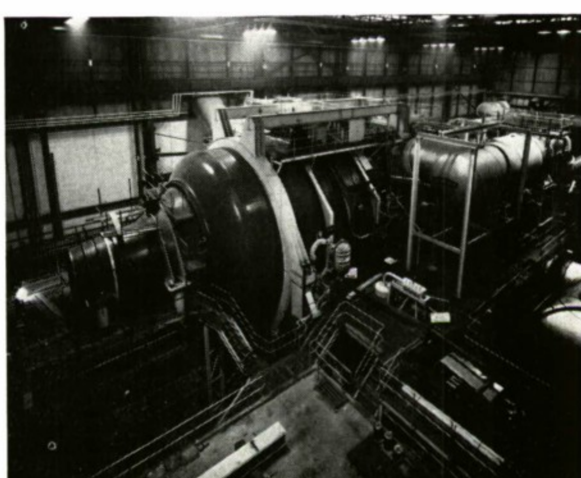


FIG. 5. General view of Cell 4. Plenum chamber in centre, exhaust system on right.

variable Mach number slotted nozzle a ramjet launch can be simulated.

Cell 2 is used for connected tests. The original test capability has been extended and the cell can now cope with high density tests of engines requiring a sea-level static air mass flow in the region of 300 lb/sec.

Cell 3 is a connected cell which can deal with the full range of engine and flight transients; the simulated flight environment can be maintained no matter how quickly the engine conditions are changed. Icing trials are done in this cell.

Cell 4 is a large free-jet cell with a variable Mach number working section and variation of incidence and/or yaw while running. It has a working section of 25 sq. ft. which enables tests of the combination of Concord intake and Olympus engine to be made over a Mach number range from about 1·7 to 2·3.

Each control room houses a large part of the instrumentation pertaining to the test in hand. In addition to some 700 engine driving and plant instruments there is a comprehensive system of measuring instrumentation which records engine performance data such as temperatures, pressures, flows, speeds, frequencies, thrust, *etc.* Part of this data is fed in digitised form to an "on-line" computer which evaluates the engine performance as the test proceeds. Other information is passed to a central recording system with "quick look" facilities in each control room. An idea of the complexity of this data-gathering system may be gained from the fact that Cells 1 and 2 each have about 400 channels feeding information to the data centre, Cell 3 about 600 and Cell 4, 700. There are in addition in the Photographic Instrument Room some 400 manometers and 100 dial gauges, shared between Cells 3 and 4, which can be recorded automatically by camera on demand from the cell control rooms.

(b) *Operation and maintenance of facilities*

Some idea of the size and complexity of the E.T.F. will have been gleaned from the above. Add to this other plant for component testing in aerodynamic and combustion research, plus laboratories for small scale investigations, and the result is a very considerable array of plant of many different kinds. The operation and maintenance of this plant is an expensive and exacting task.

Steam and electricity are required in large quantities. The steam installation, which includes two ex-Naval Battle Class boilers, provides 750,000 lb./hr. at 400 p.s.i. and 650°F. This steam is used for three main purposes; to drive the E.T.F. compressors in conjunction with synchronous electric motors on the same shaft; in the testing of engine compressors, where the compressor on test is driven directly by a 14,000 h.p. steam turbine; for peak load lopping to the extent of 13 M.W. The steam power is complementary to the National Grid supply which is taken in at 132 kV and 33 kV to a total capacity of 160 M.W. This supply, together with the steam power and a gas turbine alternator recently being installed, totals over 200 M.W.

The four test cells of the E.T.F. are fed through pipes ranging up to 10 ft. diameter (there are over 4½ miles of pipes over 2 ft. in diameter on the site) with control valves of all types and of size up to 15 ft. diameter. Ancillary plant includes cooling tower installations, water and electricity distribution networks, communication systems, computer installations and the like.

The power costs to mount a test are very high and there is therefore a large premium warranted to ensure reliability, demanding a scheduled maintenance system which deploys a labour force of several hundreds and contains upwards of 20,000 items on card index. This work load is constantly growing as more equipment comes into service and the schedules are under constant review as to times and frequency.

Some interesting failures have been recorded, two of which are described and illustrated. It would seem that Fig. 6 is a photograph of a helical spring; in actual fact it is the thread from the nut of a 6 ft. diameter gate valve and it is one of many similar failures. Large gate valves of this type are not able to withstand the frequent operation which test work demands. They must of necessity be opened and closed without equalisation of pressure, so that gate loads are high, and instead of being operated a few times a year, as in normal service, they are operated many times a day. Wear rapidly takes place so that eventually shear occurs and the thread of the nut is left on the shaft in the

FIG. 6. Thread failure in nut of 6 ft. diameter gate valve.

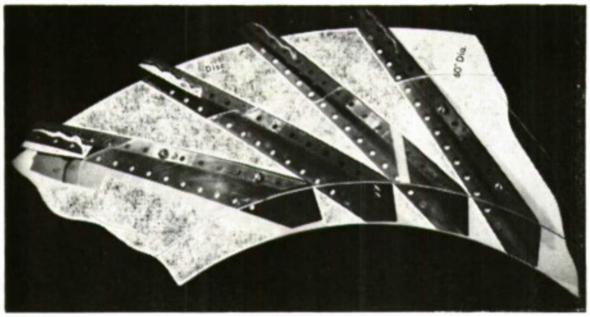


FIG. 7. Failure of impeller vanes in compressor/exhauster.

form shown. The answer has been to fit recirculating ball screws.

Fig. 7 shows a failure of impeller vanes from a 60 in. diameter high pressure compressor attributed to thermal cycling. Normally a machine of this nature, when it is used for blast furnace blowing, would go on load for many months at a time and the pressure ratio would be low. At Pyestock the machines are started and stopped two or three times a day and compressors are operated in series so that the pressure ratio and temperatures are correspondingly high. An interesting feature is the great similarity between the pieces which have cracked and in some cases detached themselves. They are almost like identical jig-saw pieces. The cure has been to use different material and restrict as far as possible the severity of the temperature cycling.

The Naval Marine Wing

The Naval Marine Wing was set up in 1948 as a joint venture with the (then) Admiralty and became operational in 1952. Its principal objectives are:—

(a) To undertake full-scale testing, including endurance trials of gas turbines proposed for Naval use, simulating as far as possible the marine installation and environment.

(b) To investigate any fundamentally maritime problems relating to the Naval use of gas turbines.

(c) To investigate problems concerning the operating and maintenance of Naval gas turbines and ancillary equipment.

A secondary but important objective is to provide a link between Naval marine engineering and the gas turbine field generally.

Today, the Wing consists of a small Naval staff with supporting civilian professional and industrial staff. Facilities, housed in the Admiralty Test House consist in the main of one large (100 ft. × 40 ft.) test bay, which can be subdivided as required, and one smaller bay. Electrical load tanks up to 1250 kW, and water cooling plant capable of dissipating something over 25,000 h.p. are available and cooling tower arrangements are such that the provision of additional cooling capacity would be a relatively simple matter. Space for rig work on ancillary equipment, a small workshop, and a small laboratory, used at present mainly for atmospheric salt analysis, are also incorporated in the building.

Since its opening in 1952, the Wing has worked on many different projects. These have included proving and performance trials on the Metro-Vick Gatric (2500 h.p.) and G.4 (5000 h.p.) and the A.E.I. G.6 (7500 h.p.) propulsion engines; and on the Allen 1000 kW and 500 kW and the Ruston and Hornsby TA (900 kW) and TF (750 kW) turbo-alternators. The G.6 engine was endurance tested to establish component lives, including an investigation into turbine disc overheating (the cause of the failure in H.M.S. *Ashanti*) which successfully established both the basic reason and a satisfactory remedy. The Ruston TA was used for an extensive investigation, in collaboration with the Chemistry, Physics and Combustion Department, into the problems of burning residual fuel. The Ruston TF also underwent endurance trials, and modifications were developed to improve the engine ignition system. The Allen 500 kW alternator has been used for endurance trials and for trials of a number of modifications, including an improved combustion can and a " zero-staged " L.P. compressor, which have enabled the engine to be uprated by some 20 per cent.

The recently adopted M.O.D. policy of using wherever possible fully developed aircraft engines, with the minimum of modification (thereby taking advantage of the extensive development effort applied to such engines) has brought about a very considerable change in the Wing's work (and in the physical appearance of the test beds !). Whereas in the past effort has been mainly concentrated on mechanical development of the engine as such, this is now neither practicable nor desirable, and it is therefore possible to concentrate much more on efforts to define and to simulate the " marine environment."

Engines currently under test are the Bristol Siddeley Marine Proteus, a marinised version of the Rolls-Royce Tyne (see Fig. 8) and, in the generator field, a Centrax CS 600-2 engine with a 500 kW alternator and (later) a waste-heat boiler. The Proteus is being used in a dual rôle, to assess its long-term endurance and for investigations into engine intake layouts. The Tyne is being examined for its suitability (after some engine alterations) as a propulsion and generator engine for the future. The Centrax engine is at present being evaluated

for H.M.S. *Exmouth,* and also, when the waste-heat boiler is fitted early in 1967, as an example of a " total heat " plant (in which the high part-load fuel consumption characteristic of the simple robust industrial engine is compensated for by the use made of its exhaust heat).

Evaluation and simulation of the marine environment can be subdivided into three components. Ship movement and shock is the most obvious, but as simulation of this is not deemed economically practicable, no work has been done on this in the Wing. The second component is the operating cycle, which imposes thermal stresses on the engine and loads on the governing and control system. Simulation of this is relatively simple, given sufficient " user-data " from ships, and engines are run at Pyestock on cycles designed to be rather more severe than the worst which can be foreseen for operation at sea.

The most difficult component of the marine environment to simulate is salt. After several years of work, and many sea trials, it is believed that the capability to assess with reasonable accuracy the total salt burden likely to be found in the atmosphere, in any but the very worst of weather, is almost within reach. Simulation of this, however, depends on knowledge of particle size, and in this respect the work is much further behind.

Arising directly from the above, a great deal of effort has been directed to means of removing salt from the air, either by suitable intake design or by filtering devices. So far, most of the work has necessarily been empirical, but it has recently become possible with the success of the specific empirical work, to make a start on the general problem.

Evaluation of the problems caused by salt in the fuel will be the subject of future work.

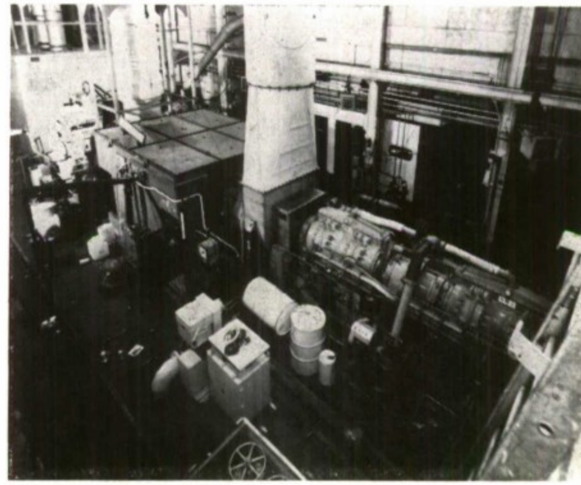


FIG. 8. Rolls-Royce *Tyne* engine on test in main test bed area of Naval Marine Wing.

Conclusion

The spectacular development of the gas turbine, and particularly its use for jet propulsion, has affected the design and performance of every type of aircraft, enabling the boundary of manned flight to be pushed well into the supersonic regime and bringing the concept of direct engine-produced lift into the realm of practicability. Future progress in engine technology will be more difficult, requiring greater skill and understanding, but there can be no question that great opportunities still exist to secure improvements in overall economy on conventional aircraft and to invent new modes of operation and flight systems which will expand the scope of air transport. In parallel, there are equal opportunities to develop the potential of the gas turbine and associated technology over a wide front, making maximum use of the ideas explored and the hardware evolved for aircraft propulsion.

A Voyage In The SIR WINSTON CHURCHILL

W. J. Spalding, R.N.S.S.
Admiralty Underwater Weapons Establishment

When I first saw the schooner she looked very small; she was tied up alongside the quay in Avonmouth Docks with the stern of a very large cargo ship seeming to hang right over her. I arrived at the shore end of her gangplank and was told by one of her crew to go down the forehead hatch where I would be told what to do. I walked up to the hatch and found it to be very small with a vertical ladder going down. I descended with great difficulty as I had a very large kit bag, but on reaching the bottom I was very surprised.

The trainees' quarters looked very spacious and comfortable. The red lino floor sloped away from me, standing in the bows, and the sides widened with the shape of the ship. There were two tables in the centre piled high with grey shirts, blue jumpers, and jeans. There were about a dozen boys standing around, most of them in ordinary clothes, and about three with *Winston Churchill* jumpers on. At one of the tables sat a very scruffy boy with patched up jeans on and long curly hair. He was the bos'n's mate.

He asked my name and introduced me to my watch leader. He told me to pick out a jumper, shirt and pair of jeans. This I did and signed for them in his book. Next my watch leader showed me my berth and told me to put on the clothes. This I did and I was then told to go to the chart-room which was just below the bridge, and take all my money and passport with me.

I found the chartroom and went in—the captain, the chief officer, and the purser were sitting round a table. I shook hands with all of them, and the captain told me to give all my money and passport to the Purser and he would look after them for me. This I did and was told to go back to the trainees' quarters.

At about seven o'clock that evening the Captain came to our quarters and gave us a talk about the coming trip. He said we would sail early Tuesday morning; he hoped to go first to Fowey in Cornwall, but it depended on the weather. He told us how the watch system worked on the ship. The day was divided into five four-hour watches and the two two-hour watches called dog watches. These two dog watches split the main watches up so you didn't do the same watches two days running. He then handed out different coloured armbands, with numbers on them. These split the 36 trainees into three groups, the fore watch, the mizzen watch, and the main watch. There was a Watch Officer in charge of each watch, with a watch leader under him. I was in the fore watch.

Monday was taken up with showing us different things on the ship, fife rails, belaying pins, halliards, *etc.* We were shown how to steer by

Mr. Spalding is a Craft Apprentice in his fourth year at AUWE. He was sponsored for this voyage by Weymouth Round Table.

compass or degrees of rudder. We also climbed the mast and went out along the upper yardarm which was about 70 feet up. To go out along the yardarm you had to lay over it on your stomach with your feet on a rope which was hung below the yardarm. We were not forced to go up, and I was surprised that about 25% did not.

We motored through the lock gates early Tuesday morning, and by nine o'clock were in the Bristol channel with three sails hoisted. I went on watch at mid-day and when I got on the bridge I was shown Cardiff on our starboard side. A severe gale had just been forecast for our area, but everyone thought it to be wrong as the weather was perfect; at eight o'clock p.m. however, when I came off watch the sea and wind were starting to get bad. I went back on watch at midnight and the wind was gusting force 11. There were gigantic waves rushing up from astern and there were only four trainees and our watch leader fit, as the rest were badly seasick including our Watch Officer. When we relieved the other watch they told us that it took two to hold the wheel, so two trainees took the wheel, and the other trainee and I were posted as lookouts.

After about half an hour the two on the wheel were so tired that we had to swop about. The other trainee and I took the wheel and it was like a live thing: it was very difficult to hold the ship on course. Every now and then a wave would come underneath the ship and we would surge forward on its crest for about 30 seconds and during this time the wheel was impossible to turn, but as the wave passed, we usually managed to get back on course before the next wave. Just before four o'clock a.m. the ship rolled heavily causing the watch leader to fall and roll across the bridge; as he rolled across head over heels he banged into the Captain's leg and squashed it against a bulkhead. When the ship steadied the watch leader got up unhurt but the Captain looked to be in great pain, and went below. The following morning I found out that the Captain had broken his ankle.

At about nine o'clock the same morning we were told that the storm had blown us many miles off course and we were now quite close to the Irish coast, along which we would try and find a sheltered anchorage where we could rest for a day and repair any damage done by the storm. It was a very clear cold day and we sailed with the rugged shores of County Cork on the horizon, off our starboard side all day. We sighted the Fastnet Rock late that afternoon, and sailed into a picturesque bay dropping anchor just as the light was fading.

This small bay was protected from the sea by three small islands, with a few cottages on them. On the mainland was a small village called Skull, nestling at the bottom of a rocky heath-covered hill. The next day was very warm and sunny, and we spent the morning painting the ship and repairing torn sails. Just after dinner an Irish fishing boat came out to us with a reporter and cameraman aboard. They stayed for about half an hour, and then went back to shore with about 20 trainees aboard including myself.

The village of Skull consisted of farmers, fishermen and a few retired English people. A few of us decided to climb the hill at the back of the village, but the distance was deceptive and we only got half way up before it was time to turn back. Even from that height, though, the view was beautiful, with the schooner anchored in the very blue bay, and just a few cottages in sight on land; it could just as easily have been the 19th Century.

Early the next morning we pulled up the anchor and set sail for England. A school of porpoise

joined up with us about mid-day and stayed with us until we got to England. All the first day out the wind was about force 5 and we were travelling at an average of seven knots, but during the night the wind dropped. The next day the Scilly Isles were in sight and it was very warm and calm. We put up full sail that morning and there was a lot of fun as each watch tried to get the sail up quicker than the other watches. But even with full sail we did not arrive at Falmouth until it was dark. We had some difficulty finding the buoy. After a bit of searching with a spotlight and a customs launch guiding us we eventually tied up.

The next day was Sunday and a boat ashore was organised for anyone wanting to go to church. The rest of the morning was spent in cleaning the

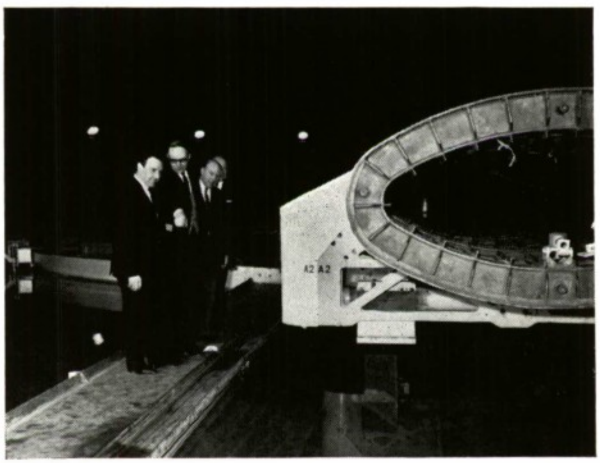
ship up. At dinner time we were told that a coach trip had been arranged for that afternoon for anyone who wanted to go. The trip was along the South coast of Cornwall to Lands End, then back along the North coast and down to Falmouth.

Early Monday morning we went alongside a pier and loaded up with stores, then motored out into the Channel. When we got out to sea we hoisted all the sails, but there was not a breath of wind and we stayed there all day. That night we got a bit of wind and started to sail up the Channel towards Portland. We were off Portland the following morning and we then tacked so that we could sail across to France. But the wind stayed about Force 2 and by that night we were still some way off the French coast, so we had to sail up and down the coast all night. At about two o'clock in the morning the wind came up to gale force and we had to take some sails down, which was very difficult at night.

The next morning with the wind still blowing strongly we sailed into Cherbourg harbour. As I was working with the bos'n that day, I was detailed for buoy jumping. This consisted of being lowered in a small boat, motoring up to the bows of the ship and taking a mooring rope, then going out in front of the ship, quickly jumping on to the buoy and tying the mooring rope on before the ship got too far from the buoy. This we did without any difficulties until we jumped on the buoy which I thought was painted white, but the white turned out to be bird droppings and they were very slippery. I just managed to grasp the ring on the buoy and put the rope through, but I didn't smell too good for the next couple of days.

We had a look around Cherbourg that day. The next morning we sailed back across the Channel, dropping anchor in Sandown Bay that night. On the way across we passed very close to the *Queen Mary*. We left Sandown the next morning, and as there was no wind we had to motor into Portsmouth, the *Winston Churchill's* home port.

In all the trip was a great experience, and the storm made me realise how tough the men who sailed the old windjammers must have been. I am very grateful to the Weymouth Round Table and the AUWE for giving me the chance to make this trip.



Mr. Roy Mason, Minister of Defence for Equipment, being shown details of the Rotating Beam at A.R.L., by the Superintendent Mr. W. L. Borrows. They are accompanied by Mr. A. W. Ross, D.N.P.R. and Mr. F. S. Bart, Head of the Fluid Dynamics Group.

The Technology and Engineering Applications of Reaction-Bonded SILICON NITRIDE

N. L. Parr, C. Eng., M.I.Mech.E., F.I.M., R.N.S.S.
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Admiralty Materials Laboratory

SUMMARY

The use of reaction-bonded silicon nitride bodies as individual components, or in assemblies of ductile and brittle materials, for engineering application, is well established, but further expansion of the technology has been achieved and is now described, and a possible explanation of the chemical and physical processes involved is presented.

Recent experiences in production methods, and details of associated mechanical properties obtained are described together with the current experimental applications which are aimed at the establishment of an appropriate design philosophy to exploit the unusual combination of properties obtained in this material.

Introduction

Experimental production and application of silicon nitride bodies for a variety of engineering uses has increased over the last five years, and a number of publications have described early progress(1, 2, 3, 4, 5, 6, 7, 8, 9).

Further knowledge of the structure, and recent expansion of the technology now warrants a further note. This paper is therefore a state of the art survey with some pointers towards future development and experimental application.

The Reaction-Bonding Process

The route for the production of silicon nitride bodies of density between 1·8 and 2·7 gms/cc is shown diagrammatically in Fig. 1, and details of the major operations involved are as follows:—

Compacting of Silicon Powder

The final density, the controlling factors of the reaction-bonding procedure, and subsequent properties obtained, depend upon the physical and chemical nature of the original silicon powder, and on the manner in which it is compacted to a green pressing.

Silicon powder purity has a considerable influence upon the rate of conversion to silicon nitride at temperatures below the melting point of silicon. The presence of some oxygen is essential and the quantity absorbed on the surfaces of the particles appears to be sufficient. The normal impurity content of 0·8% Fe and 0·5% Al in commercial silicon powder has been found to be beneficial. Even higher levels of Fe can be tolerated and have been associated with higher strength values in the end-product. The effect of additions of titanium and calcium hydrides to the silicon powder before compacting, and the use of cracked ammonia instead of nitrogen, increases the initial reaction rate(10).

Compacting of silicon powder is accomplished by one of the routes shown in Fig. 2. Slip casting, with or without the aid of binders may be used, and by employing thin films of epoxide resin on the surface of the particles the powder can be bound stiffly enough to be shaped by machine into intricate forms (provided that a 3% shrinkage can be tolerated in the end-product by the loss of the binding agent during the early stages of firing). Burning out of binder material is conducted at temperatures below 400°C. under reduced

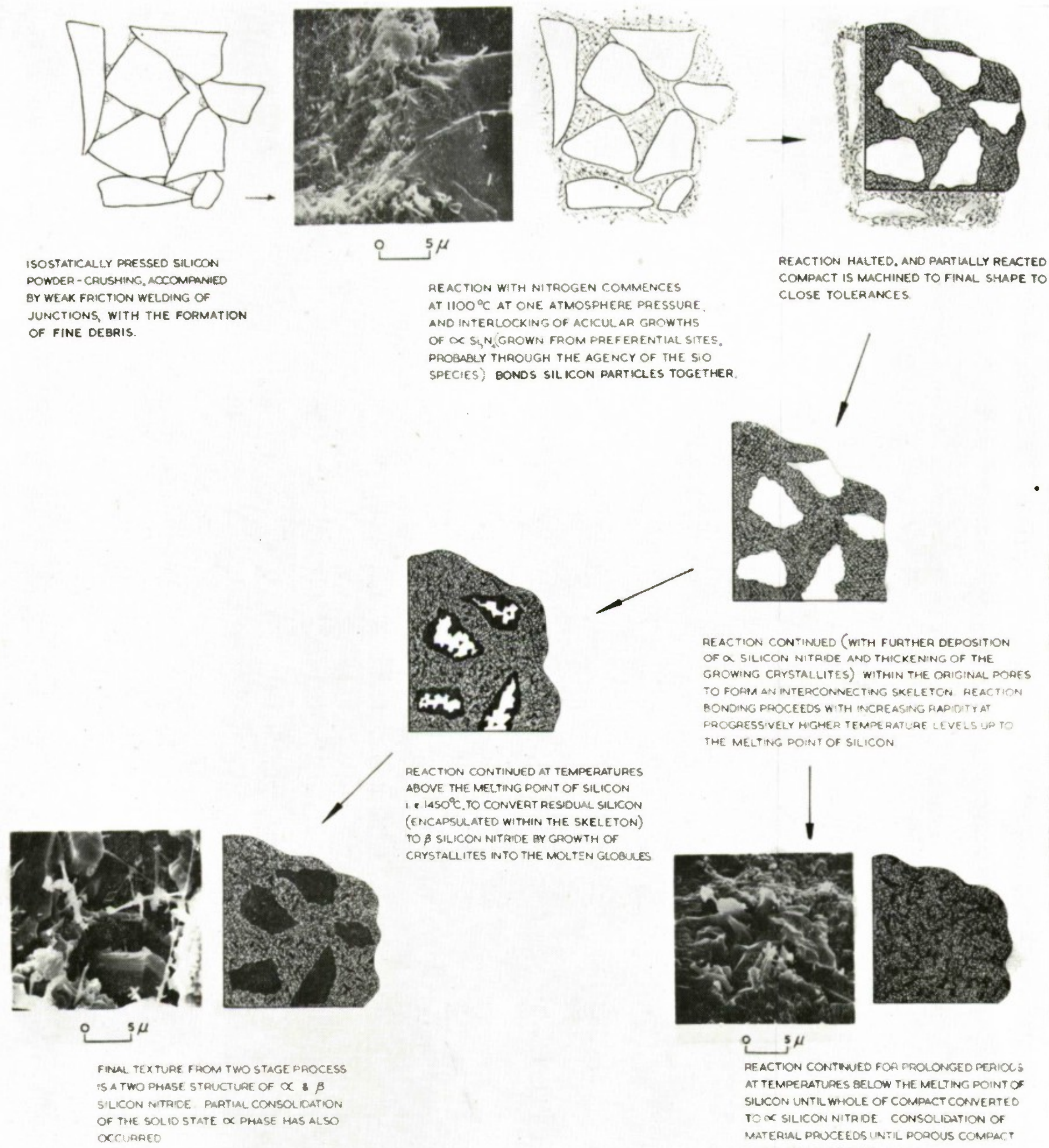

FIG. 1. Formation of single and double phase reaction-bonded silicon nitride bodies from silicon powder.

pressure in order that no carbon is dispersed inside the powder compact[11]. A further fine machining operation may be carried out after light reaction-bonding, described later, if close tolerances are required.

Pressures used in the production of silicon powder die-pressings are limited due to inhomogeneous elastic recovery and possible resultant fragmentation of the pressing during release of high loads. Isostatic pressing of powder in rubber bags removes most of these problems. Even so the maximum pressing pressure which may be used is a function of the size and shape of the compact and must be determined empirically if freedom from fissures is to be avoided. These are sometimes difficult to identify and will not be

healed by subsequent reaction-bonding, and so will constitute planes of weakness in the final product. Such fissuring is considered to arise either from occluded gas pressure or from inhomogenous recovery of compressive elastic strain in weak powder pressings. It is necessary, therefore, to design the rubber powder containment vessel to give even packing pressure throughout the compact at all stages of the isostatic pressing operation. The use of hollow bags is an obvious advantage for cylindrical sections. Agglomeration of powder prior to pressing, evacuation of the bags containing the powder prior to applying pressure, and the use of internal lubricants are other methods which can be employed to obtain sound compacts.

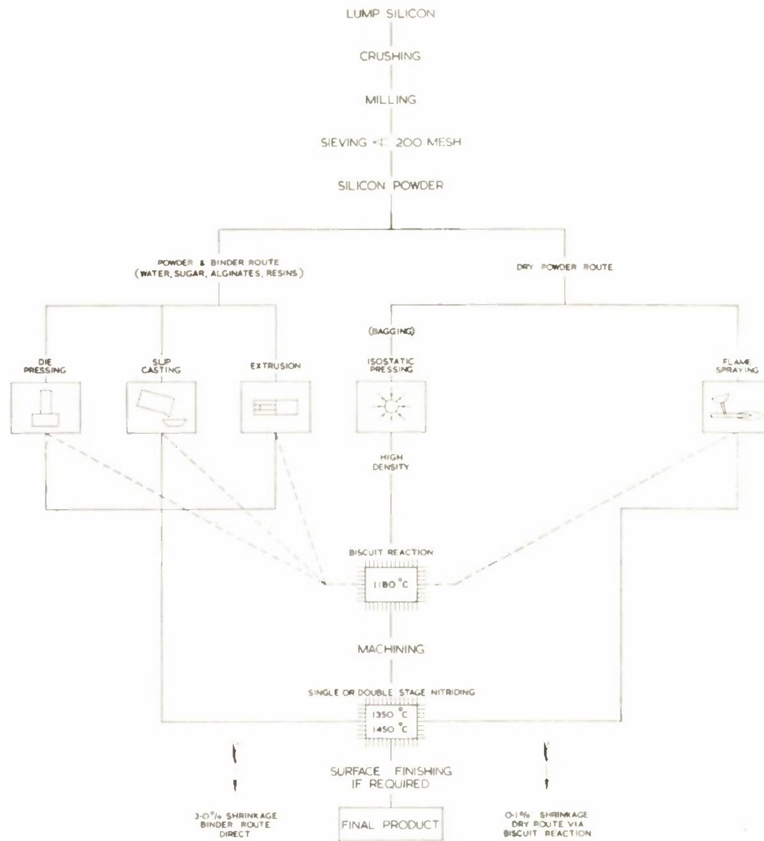

FIG. 2. Routes to the production of silicon nitride components.

Flame-spray deposition of silicon powder is particularly useful for the production of thin shells and delicate shapes. Deposition upon shaped formers, previously coated with a release agent such as sodium chloride, can be achieved with standard powder spray-gun equipment, and the density of the deposited material, and resulting silicon nitride, can be varied over a wide range. It is, however, essential to avoid sintering during flame deposition of the silicon powder as this opposes subsequent reaction-bonding.

Other methods of powder compaction include extrusion and electrophoresis, and some assemblies of silicon nitride components can be bonded together in the green or biscuit fired condition by mechanical jointing with the application of a slurry of fine silicon powder between the mating surfaces prior to the final reaction-bonding.

Reaction-bonding

The formation of silicon nitride crystallites within the pores of the powder compact commences as whisker growth at approximately 1,150°C. at 1 atmosphere pressure of nitrogen. The presence of moisture, oxygen and hydrogen inside the pores of the compact appears also to be essential for the growth mechanism to proceed. The chemical reactions surrounding the formation of silicon nitride, and its condensation at the tips of growing whiskers, have been postulated by Lewis[12] and involve the formation of Si_3N_4 from SiO vapour in the presence of nitrogen and hydrogen. Side reactions with other elements present—such as carbon, iron and aluminium occur also, and there is constant local diffusion and recirculation of reacting gases.

Chemical and physical conditions possibly change during the reaction bonding process to permit side growth and thickening of the whiskers so that the final result is the formation of an inter-penetrating aggregate of crystallites, which gradually replace the original silicon powder.

Subsequent rate of crystallite growth, and a complete conversion of the silicon powder compact to silicon nitride, can be accelerated by raising the temperature to as near to the melting point of silicon as practicable without collapse of the powder compact by local or general melting. A slight exothermic reaction contributes to the increase in temperature and must be allowed for in furnaces of low thermal capacity.

The various stages of the procedure, and the variations which can be employed to produce different textures have been shown diagrammatically in Fig. 1, and the time for complete reaction

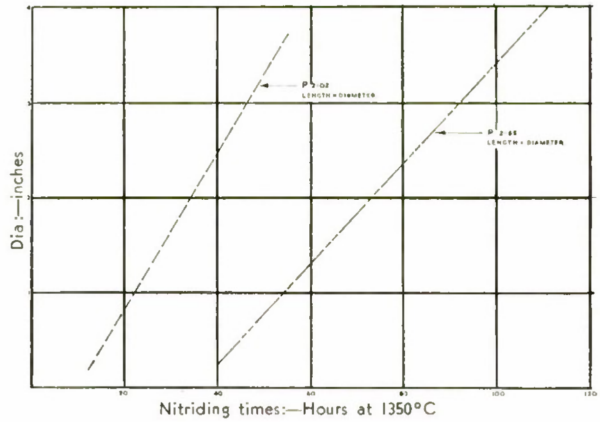

FIG. 3. Times for complete solid state nitridation of silicon cylinders of varying density and diameter.

in relation to the size and density of the original powder compact is shown in Fig. 3.

The conversion of silicon powder compacts to an interpenetrating aggregate of silicon nitride crystals by the reaction-bonding process results finally in a polycrystalline structure with a porosity of between 15 - 30% depending upon the original density of the powder compact. Complete reaction of higher density pressings at temperatures below the melting point of silicon can be a long process as the thickening skeleton provides increased resistance to nitrogen mobility, and the material produced under these conditions is almost entirely of the α form.

Nitriding time may be considerably reduced if, when the skeleton is sufficiently dense to retain molten silicon droplets, the reaction temperature is raised above the melting point of silicon. Under these conditions conversion of the dispersed droplets of silicon to silicon nitride proceeds by the nucleation and growth of crystals of β silicon nitride to produce polycrystalline islands of β of theoretical density in the original α matrix. Even after prolonged solid state nitriding it is advisable to hold the almost complete nitrided body for a few hours at 1,450°C. in order to remove completely all traces of residual silicon, particularly where maximum electrical resistivity and dielectric strength are required. Alternatively, heating at these temperatures in air or oxygen will convert the residual silicon to silica to produce a silicon nitride/silicon dioxide product (the properties of which have not yet been fully evaluated). A typical nitriding schedule for biscuit fired material of 2 in. cube produced from a high density powder pressing is 1350°C. for 50 hours followed by 1,450°C. for 10 hours. This should give about equal proportions of α and β phase in final material having a density of 2·6 gms/cc.

The proportion of α to β phase, and to some extent the texture, depends on the particular production schedule chosen, while mechanical properties are governed mainly by the density of the original powder compact. No dimensional change occurs after the first skeleton of silicon nitride has been laid down in the pore spaces, *i.e.* between the partially fired and machined state, and the fully reaction-bonded product.

Machining

At the Partly Fired Stage

The machinability of the partly fired material is a function of the degree of reaction-bonding imposed on the powder compact. However, by arranging for a soaking period around 1,050°C. sufficiently long to ensure even temperature distribution, followed by about an hour at 1,150°C., material is produced to be sufficiently strong to withstand the clamping pressures, yet still friable enough to be machined.

Machining, in fact, is more a process of rubbing away the loose particles rather than a cutting action, as with metals. With milling and drilling operations pressure can be built up at the cutting edge of the tool, such that when the tool breaks through at the end of the cut the material will fracture and crumble away over a large area. It is preferable therefore to work from two sides to meet in the centre of a slot or a hole to prevent this breakaway.

Care must be taken, particularly when drilling, because the loose powder above the cutting tip will wear away the freshly drilled part of the hole and increase its size. The loose powder must be removed continually during this operation to preserve the accuracy of the hole.

Normal high speed steel tools are generally used for machining the partly fired material, although wear is still quite considerable in some instances. Where the material is too hard for high speed steel, as a result of incorrect partial reaction-bonding, tungsten carbide or diamond tipped tools may be used, but only where absolutely essential since the pressure build up is significantly higher. Normal cutting speeds are slightly lower than those usually employed for the machining of cast iron.

Grinding in the partially reaction-bonded state is perhaps the easiest process, where appropriate, using a standard coarse, general purpose, wheel. Again, the softer the specimen the easier it is to work. Harder samples tend to break in contact with the wheel. As with all other machining processes for silicon nitride, cutting fluid must not be used during the grinding operation. Holding the work piece is one of the major difficulties and

great care must be taken not to fracture the stock material when using vices, clamps and chucks.

Powder removed during shaping operations is hard and abrasive and precautions must therefore be taken to protect all exposed moving parts of the machine. Plastic covers can be used on slides and lead screws, and local vacuum extraction heads help to reduce the problem. Normal practice is to set aside machines to work exclusively on silicon nitride. Ideally, machines should be provided with adequately protected parts, and at all times efficient extraction of fine airborne particles should be mandatory for operator protection.

Final Machining

The only satisfactory method found so far for machining fully reaction-bonded silicon nitride is grinding using a diamond wheel, or possibly certain grades of carborundum. Here a cutting fluid can be used and thus the problems of protection are not so severe. Since the final material is extremely hard, holding is not such a problem as in the soft state, although care must still be taken because of the brittleness of the material. An example of a complex rotary valve machined from partial reaction-bonded bar-stock, followed by full nitriding, and finally dressed in the piston ring grooves by diamond grinding, is shown in Fig. 4, together with a variety of other components produced to close tolerances by the same technique.

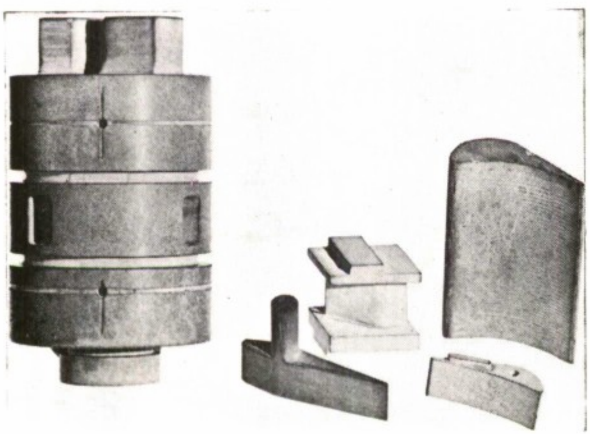

FIG. 4. Silicon nitride components produced to fine tolerance.

Properties

A general survey of the mechanical, physical and chemical properties of material produced by variations to the above production procedures are given in Table 1 and Figs. 5, 6, 7, 8 and 9.

TABLE 1. Properties of Reaction-Bonded Silicon Nitride

Thermal Properties		
Coefficient of Thermal Expansion	$2{\cdot}5 \times 10^{-6}/^{\circ}C$ 20 - 1000°C	
Thermal Conductivity (room temp.) P 2·65	0·02 - 0·05 cal. cm/cm² sec. °C	
Decomposition Temperature	1800°C at 1 Atmosphere N_2	
Thermal Shock	Superior to all other known ceramics and comparable with metals	
Creep Strength	0·5% strain in 1000 hours at 1200°C load 1½ T.S.I. (2·5 gms/cc.)	
Electrical Properties		
Resistivity	20°C 400°C 700°C 1050°C 10^{13} 10^{11} 10^{8} 10^{6} Ohm. cm. (DRY)	
Dielectric Constant	9·4	
Dielectric Loss at 1 Mc/s (tan δ)	0·001 — 0·01	
Corrosion Resistance		
Resistant to Atmospheric Oxidation up to 1600°C		
Not Wetted by Common Metals except by Cu and Cu Alloys		
Resistant to all Acids except HF		
Attacked by KOH at 400°C, Na_2SO_4 and V_2O_5 at 1000°C		
Manufacturing Stability		
Dimensional Change During Nitriding less than 0·1%		
Chemical Formula		
Si_3N_4		
Crystal Structure	Alpha Phase	Beta Phase
Hexagonal Lattice Constants	a 7·48 ± 0·001 c 5·17 ± 0·001	7·608 ± 0·001 2·910 ± 0·0005
Theoretical Density		
α 3·184 β 3·187 gm/cc		
Bulk Density		
1·8 – 2·7 gm/cc	Corresponding Porosity 44% – 15% Pore Size Approx. 100 Angstroms	
Mechanical Properties		
Transverse Rupture Strength (average values) (p.s.i.)	ρ 2·2	ρ 2·65
at 20°C	17,000 p.s.i.	28,500 p.s.i. *—30,370 p.s.i. 30,000 p.s.i.
at 1300°C	19,000 p.s.i.	*35,000 p.s.i.
With 2% Fe at 20°C	22,500 p.s.i.	36,000 p.s.i.
	* All α Phase (single stage Nitriding)	
Tensile Strength (p.s.i.)	P 2·0 $11{\cdot}5 \times 10^3$ ρ 2·4 18×10^3	ρ 2·65 $20{\cdot}5 \times 10^3$

Youngs Modulus (p.s.i.)	ρ 2·0 14×10^6 ρ 2·4 $24{\cdot}66 \times 10^6$ ρ 2·65 $31{\cdot}75 \times 10^6$
Hardness	V.P.N. 1000 – 1200 Moh > 9
Compressive Strength (t.s.i.)	35 – 50
Coefficient of Friction	P 2·5 Diamond Polished

Load p.s.i.	9	15	28	75
Static	·105	·11	·13	·15
Sliding	—	—	·12	—

(0·7 at 600°C)

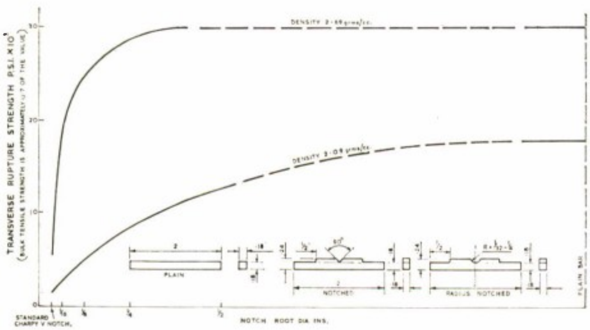

FIG. 5. Transverse rupture strength of silicon nitride on plain and notched three point loaded beams.

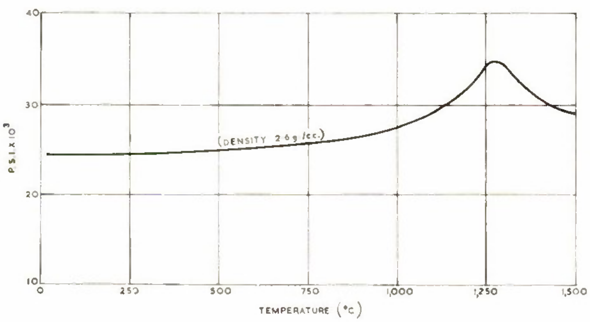

FIG. 6. Transverse rupture strength of reaction-sintered material at various temperatures.

Tensile strength was measured by hydraulically loading a thin ring test piece (2 in. o/d, 0·1 in. thick, 0·6 in. wide), in the equipment developed by the Stanford Research Institute, California and detailed in Fig. 10. Using thin shell formulae, and surface strain gauges to measure the elastic strain, it was possible to study the effect of density and texture of silicon nitride on the ultimate tensile strength and elastic moduli. Results are given in Fig. 11 from which the average tensile strength obtained for high density material (2·6 gms/cc) is given as 8·5 t.s.i. and 4·5 t.s.i. for low density

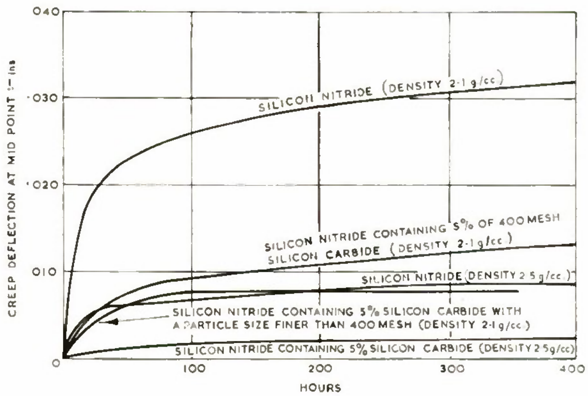

FIG. 7. Creep resistance at 1200°C. (4-point loaded beam 18 in. × 18 in. × 1·5 in. Total dead load 1·5 T.S.I.).

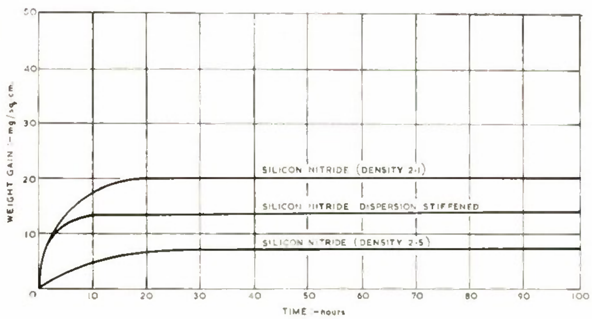

FIG. 8. Oxidation resistance at 1200°C.

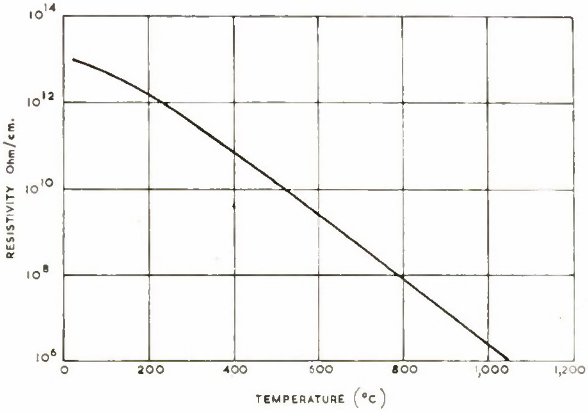

FIG. 9. Resistivity of reaction sintered silicon nitride (Dry).

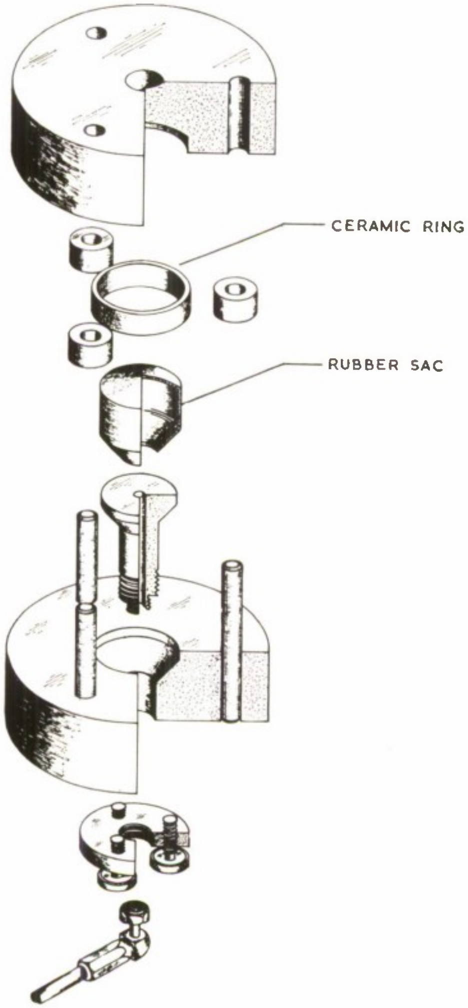

FIG. 10. Tensile test rig developed by Stanford Research Institute, California.

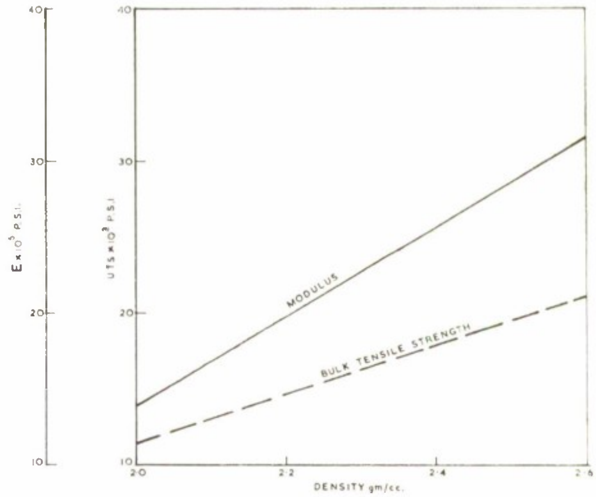

FIG. 11. Relationships of elastic modulus and bulk tensile strength to density of silicon nitride as determined by hydraulically loading thin rings.

material (2·0 gms/cc). It can be seen that the modulus of elasticity increases more rapidly than the ultimate tensile strength with progressively higher densities.

Transverse rupture strengths of 3-point loaded beams in relation to density have been given in Fig. 5, and if these results are compared with those obtained using the thin ring test, surface tensile strength may be assessed as 0·7 of the bulk cross breaking strength for plain bars. Transverse rupture tests were also carried out on notched bars to study the effect of acuity, and the results are given in Fig. 5. It was observed that higher density material was less notch-sensitive except in the extreme acuity range. This means that where high surface finish, and smooth contours, cannot be ensured and maintained, safe working tensile stresses should not exceed 2·75 t.s.i. for densities of the order of 2·6 gms/cc and 1·5 t.s.i. for densities of the order of 2·0 gms/cc. These figures have been assessed on the lowest results of numerous duplicate tests where the scatter was in all cases within 15% of the mean value.

No evidence exists of the accumulation of fatigue damage in this material, and so a nominal safety factor of, say 2·0, can be employed with confidence on the results reported. This means that safe tensile working stresses are low, and design is therefore constrained to make maximum use of the low density and good compressive strength of the material, and to provide ingenious means for reducing surface tensile stresses to a minimum.

Transverse rupture strength increases slightly at temperatures up to 1,400°C., although the material may be used at temperatures up to 1800°C. at 1 atmosphere pressure of nitrogen when it begins to dissociate into its component elements.

Friction and Wear

In view of the hardness, high temperature stability, oxidation resistance and production to close tolerance of silicon nitride components, the material is considered to have potential for bearings, particularly for use at high temperatures with solid lubricants.

Co-efficients of friction, and wear resistance, have been assessed on experimental journals and plain bearings of the type shown diagrammatically in Fig. 12. Clearances between sliding surfaces appear to be critical and a function of speed,

temperature, and bearing load. For instance, under light loads at high speeds and room temperature using graphite or boron nitride as a solid lubricant, with a ·001 in. clearance, the co-efficient of friction between silicon nitride components is less than 0·2, and wear resistance is negligible after 12×10^6 cycles, with self-polishing of the rubbing surfaces, as may be seen in Fig. 13. At elevated temperatures (*i.e.* up to 1,000°C. and possibly as high as 1,600°C.) it is essential to employ clearances up to 0·003 in. on 1 in. diameter bearings. Means must also be provided for collecting minor debris, and dispensing solid lubricant over the surface, particularly during the running-in period. Under these conditions silicon nitride journals and bearings will operate satisfactorily with co-efficients of friction varying from 0·3 at ambient temperature to 0·7 at 1,000°C.

Tests on mixed bearing assemblies of silicon nitride rubbing against Nimonic 90 and H.R. Crown Max give good results, with co-efficients of friction varying from 0·1 to 0·4 at temperatures up to 800°C.

Design Considerations

Silicon nitride takes a unique place among materials of construction available to the designer in view of the novel route for the manufacture of components to close tolerances, and because of its unusual combination of properties (in particular its low co-efficient of expansion, which provides outstanding thermal shock resistance and low residual thermal stress gradients in high temperature structures). The material has low density and hence a reasonably high specific strength. Furthermore, as compared with other brittle materials, components of complex shape, manufactured to tolerances of the order of ±0·001 in. are relatively inexpensive.

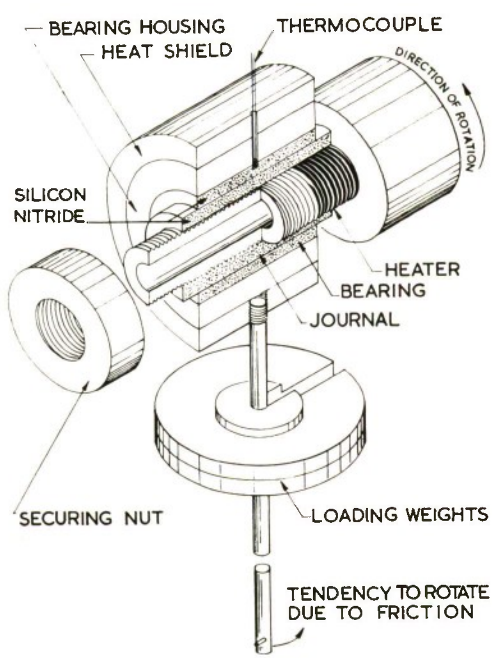

FIG. 12. High temperature bearing test.

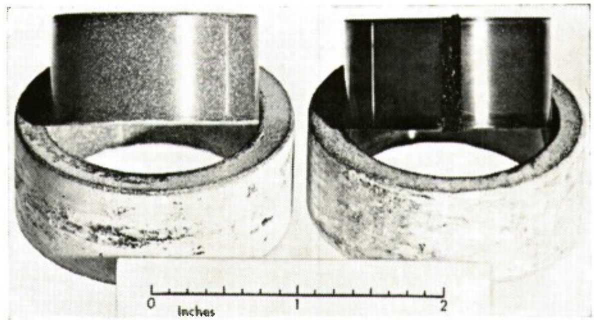

FIG. 13. Silicon nitride bearings before and after service showing self glazing habit. The graphite fibre brush shown on the right hand inner ring collects debris and dispenses a lubricating smear of graphite over the surfaces.

The material is, however, brittle, and surface stresses exceeding the elastic breaking strength will result in a sudden catastrophic fracture. It is necessary therefore to take a number of factors into account during design if advantage is to be made of the unusual combination of properties obtained.

In general, the application of non-ductile materials to design should take the following points into account:—

1. Every known method must be employed to prevent crack initiation by ensuring that the surface or local tensile stress remain well below the elastic breaking strength of the material.
2. Compressive stresses should be employed wherever practicable.
3. Failure probability must be established on actual components under actual operational conditions.
4. Non-destructive proof testing must be carried out on all components.
5. Stress concentration effects arising from design (*e.g.* sharp corners and edges) and operation wear (*e.g.* groove formation) must be avoided.

With regard to 1. above the ultimate tensile strength of the material has been established with the pneumatic ring test with good reproducibility of results. Safe surface tensile working stress can be determined from compound elastic stress

analysis, and the design of components then established with a suitable safety factor (*e.g.* 2·0). Photoelastic techniques are particularly useful for studying stress patterns in view of the purely elastic behaviour of the material.

Metal reinforcement, either by the use of backing plates, collars, or internal metal cores, can be employed provided that high stresses attendant on differential thermal expansion or contraction can be covered adequately. Advantage of the high thermal shock resistance of the material can be taken to cast or forge internal metal reinforcement *in situ*. Mechanical power take-off points can sometimes be compression loaded to offset tensile stresses. An example of some designs for a variety of proved and experimental applications are given in Figs. 14-17.

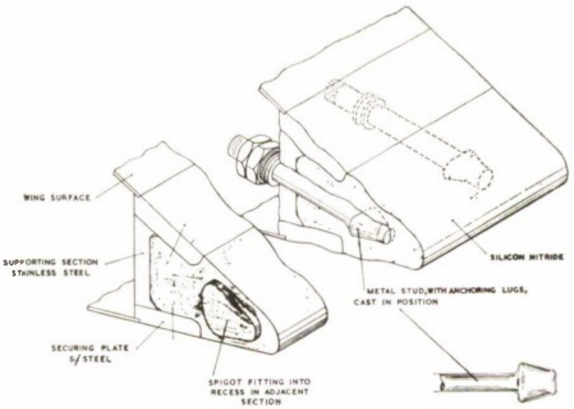

FIG. 14. Silicon nitride leading edge; tentative scheme.

Future Development

Further improvement in the strength of silicon nitride by development of the basic nitriding process in its present form is not anticipated but several alternative avenues are open for exploration. The first of these is aimed at increasing the stress required to initiate cracking by surface densification and smoothing, possibly by plasma deposition. Some success has already been achieved by surface decomposition followed by renitriding of the deposisted silicon, but more effort along these lines is urgently required. Surface metallising or glazing with silicates can be carried out on finished components but these aspects also require further study.

Another possibility requiring attention is to strengthen the bulk material by the incorporation of whisker or fibre reinforcements. Metal, glass coated metal, and silicon carbide fibres are being investigated, and mismatch of co-efficients of thermal expansion and elastic moduli are being considered as means of increasing strength and stiffness by internal compressive stressing; alternatively, for conferring toughness by internal redistribution of strain energy in a similar manner

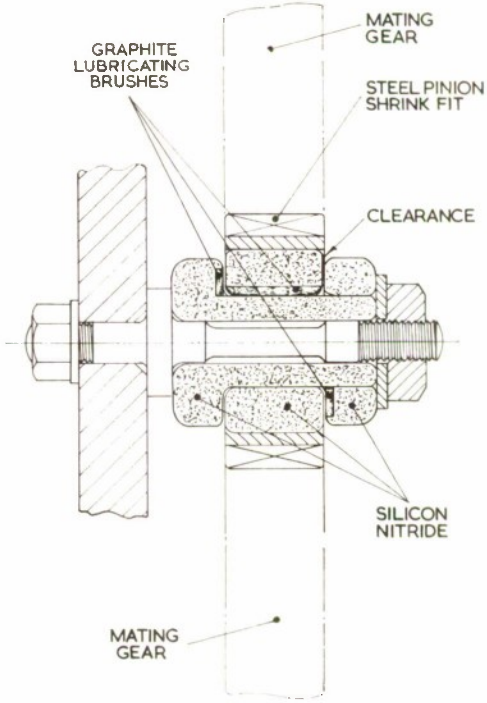

FIG. 15. Design of dry ceramic bearing.

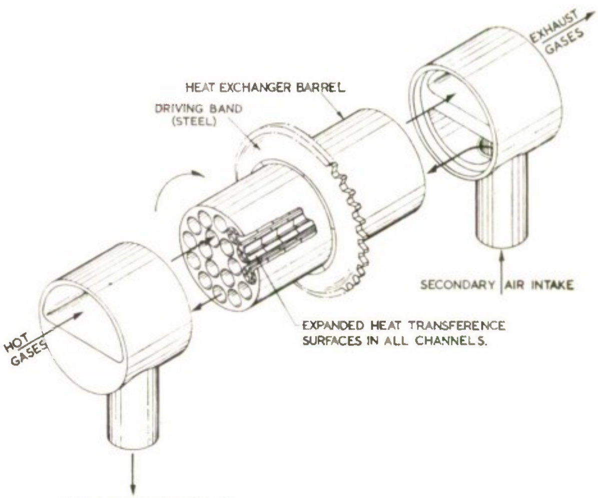

FIG. 16. Rotary heat exchanger constructed entirely from silicon nitride.

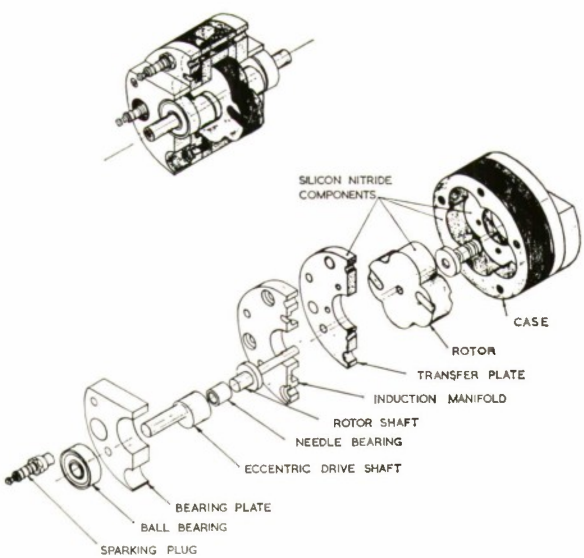

FIG. 17. Rotary piston engine employing silicon nitride rotor, stator and side plates to improve wear, resistance and sealing.

to that employed for glass reinforced plastics. Problems being encountered include chemical stability and compatibility during nitriding operation, and the formation of critical bond strengths between the reinforcements and the matrix material.

Application to engineering design is now demanding increases in the size and complexity of components. This in turn requires larger production equipment, particularly for the manufacture of sound powder pressings for the production of homogeneous partial reaction-bonded machinable stock, and for the final nitriding of large machined shapes. Economy in material and operating costs are constantly being borne in mind, and there is a tendency, where possible, to move towards the production of isostatic powder pressings close to the final shape required by using hollow rubber bags, backed where possible with perforated metal stiffeners. Recently, considerable advances have been made in the production of components by spray deposition of powder shapes as shown in Fig. 18. This is not only providing an economical route for the production of a wide variety of components, but enables graduation in density within a component from 2·0 to 2·8 gms/cc. by varying the mode of deposition.

Gas fired furnaces are being developed for the reaction-bonding of larger shapes owing to the strain imposed on resistance elements in large electrical furnaces. It is hoped that deoxygenated air can ultimately be used as the furnace atmosphere in place of pure bottled nitrogen. Thus, the original object, to produce a low cost material of construction possessing unique room and high temperature properties, from two of the most common elements which chose not to combine together when the earth's crust was formed, has been substantially achieved.

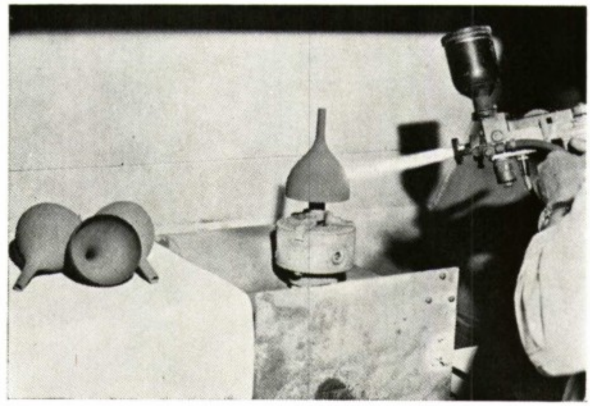

FIG. 18. Flame spraying on to a steel former.

Acknowledgement

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A Continuity Tester for Multicore Cables

F. R. Woolven, R.N.S.S.
H.M.S. Excellent

Introduction

The checking for continuity between terminal ends of multiway connectors using lamp/buzzer and test prods/clips is a slow and visually difficult process, especially with the trend towards miniature high density connectors.

A unit is described in which the cable to be tested is fitted to appropriate panel mounted plugs/ sockets, and a simple switch operation checks all connections for continuity in sequence at a rate of approximately 50/second.

Lamp indication is provided if all lines are correct, or, in conjunction with a rotary switch, to indicate the location of the open circuit line.

Provision is also made for "jumping" the open circuit position to continue the testing sequence. The loading imposed on the cable cores is approximately 100 mA maximum and the applied EMF is 24V d.c. It is therefore within the limits likely to be encountered on miniature or sub-miniature plugs/sockets.

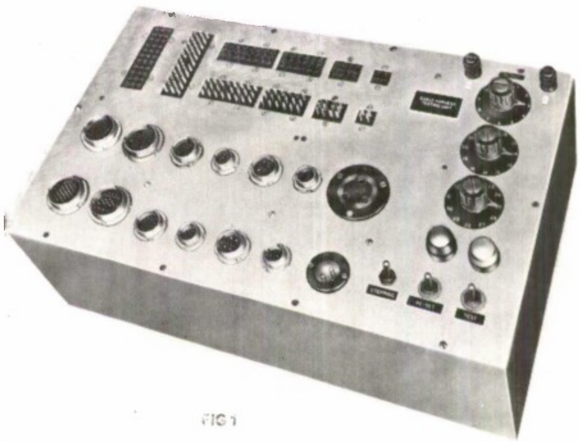
Although this unit was made up for laboratory use it is considered to be suitable for moderate production testing. For large quantity testing the screw connectors would be time wasting and subject to wear but this could be overcome by removing the threads from the fixed couplers.

General Description

All components are housed in one unit, the size of which is determined largely by the range of plugs and sockets to be tested.

Panel mounted plugs/sockets together with lever and rotary switches, indicating lamps, supply input terminals and fuzes are fitted to the top face of the panel (Fig. 1).

Three 11 way switches were used in the prototype to cater for a maximum of 33 pole plugs/sockets. (The circuit diagram refers to a single 33 way rotary switch for simplicity).



The underside of the panel is fitted with the following components:

(a) A 5 level 25 way uniselector for 24V d.c. operation with one double ended bridging wiper, and two pairs of single ended wipers in opposite phase. For the prototype unit, a standard PO Type 2 Uniselector Wiper Assembly, double ended, 5 level, one bridging (AP 63339) was modified as follows: the first pair of non bridging wipers were cut away on one side adjacent to the collector rings and the next pair also cut away but on the opposite side. It is possible to obtain wiper assemblies to this specification from the manufacturer.

(b) A simple power transistor switching unit in which a negative turn—on pulse current of approximately 100 mA drives an OC 28 transistor into heavy conduction and energises the US magnet coil in the collector supply line. A catching diode is connected to the collector/ emitter terminals to protect the transistor from the transient back EMF induced in the uniselector coil at the end of the conducting pulse.

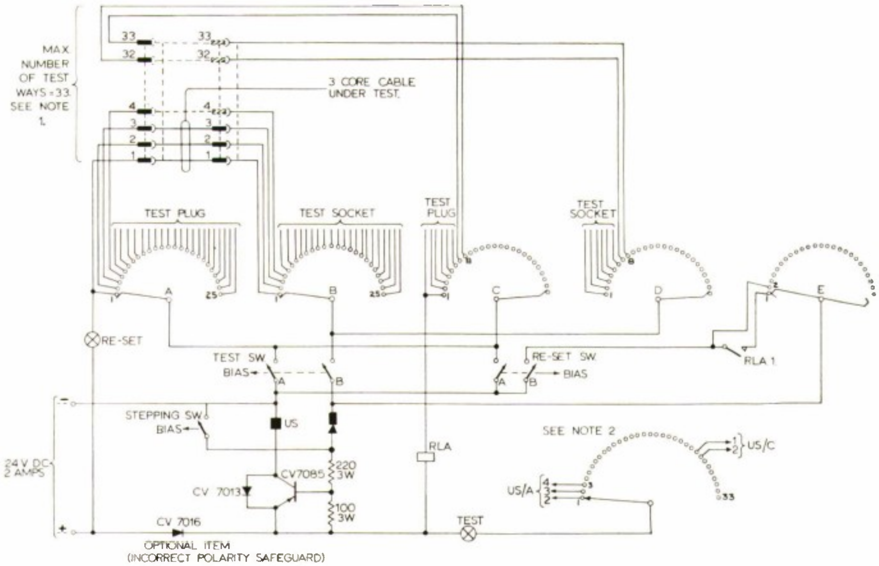


FIG. 2. Circuit diagram.

NOTES
1. ALL TEST PLUGS ON PANEL ARE CONNECTED IN PARALLEL. ALL TEST SOCKETS ON PANEL ARE CONNECTED IN PARALLEL.
2. THREE INTER-CONNECTED 11 WAY SINGLE POLE ROTARY SWITCHES WERE USED INSTEAD OF THE 33 WAY SINGLE POLE SWITCH DRAWN.

A 100 ohm resistor is connected to emitter/base for thermal stability, and forms a potential divider for the base supply with the 220 ohm negative supply resistor.

(c) Multiway terminal posts to provide the parallel connections between uniselector studs, plugs, sockets and rotary switches.

Circuit Operation (See Fig. 2)

Consider a simple case of a three core cable fitted to the appropriate plug/socket on the panel.

Setting Up

After connecting to 24 volt d.c. supply (Note: Correct polarity is important), operate the re-set switch to obtain re-set lamp indication (confirms that uniselector is in correct starting position or operates reset circuit accordingly). Set the (1-10) rotary switch to position (3).

Operation

The test switch is operated and negative supply is connected to wiper 'A' and contact A/1. This contact is common to all (1) or (A) pins on the panel plugs. If SK/1 on the test cable is connected to PL/1 on the other end of the cable, the negative supply proceeds *via* contact B/1 wiper 'B', the test switch and thc interrupter contacts of the uniselector to the 220 ohm base resistor. The power transistor conducts, the uniselector magnet is energised and, in addition to initiating the wiper movement the interrupter contacts open, breaking the negative supply to the base. This process is repeated until an open circuit is encountered, which in this case would be contact 4 on US A/B. The rotary switch has been set to position (3) in this case (connected to contact 4) and in this resting position the test lamp would indicate test OK.

Assuming that number (3) line on the test cable was open circuit, the wiper would have stopped at number (3) contact and the test lamp would have failed to indicate. The procedure then is to turn the rotary switch back until the lamp indicates; the switch position (*i.e.* "2") would then indicate the line immediately prior to the fault.

After completion of the test the re-set switch is operated to return uniselector wipers A/C to the correct starting position on contact (1). In this case the negative supply is routed *via* the re-set switch to US.E contacts 2-25 inclusive, wiper (E) and the interrupter contacts. If the wipers had rotated less than 25 contacts (as in the example quoted) wiper (E) would complete the 180 degree movement to stop on Contact 1 and this would result in wipers 'C' and 'D' resting on Contact 1. To overcome this possible out of phase operation a relay (RLA) is connected to energise at Contact 1 position of wiper 'C'; relay contacts A/1 close and bypass the normal inhibit action at Contact E/1.

The stepping switch, which provides a single shot operation of the uniselector magnet, is used to by-pass an open-circuit line and thus allow completion of the test, the rotary switch being re-set to the original test figure after identification of the faulty line.

When the test switch position is higher than (11) the preceding switch(es) must be turned to the 'OFF' position to avoid a misleading test indication.

Flux for the submerged-arc welding of Q.T.35

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SUMMARY

Submerged-arc welding is a process of great practical importance in ship eonstruetion, but the commereially available materials give weld properties below those obtainable by other, less economie processes. At N.C.R.E. the factors affecting the properties of welds in Q.T.35 have been examined and significant improvements made. An attempt has been made to explain the results by reference to the nature of the arc and the thermodynamics of slag-metal reaetions.

Introduction

The modern warship must carry a payload of men and equipment, and it must be able to resist explosive attack. Consequently the hulls are built of steels that are strong and tough, and all structural welds in the hull must similarly be strong and tough. For many years, therefore, it has been the function of the Welding Sections at N.C.R.E. and at D.G. Ships headquarters to ensure that for each generation of shipbuilding steels there were matching welding processes (machines and consumables) available. As regards steels in the mild steel range and slightly stronger there has been no shortage of welding suppliers anxious to obtain Navy Department approval for their products, but the latest shipbuilding steels Q.T.28 and especially Q.T.35 (low-alloy quenched and tempered steels of 28 t.s.i. and 36 t.is.i. guaranteed proof stress respectively) have been so far in advance of the steels currently in use in general engineering that it has been necessary for the Welding Laboratory at N.C.R.E. to take the lead in asking the welding suppliers to devise suitable welding materials. To reduce the extent of our technical dependence on the welding suppliers we have begun to perform our own basic research, within N.C.R.E. and extramurally, into the welding processes themselves and their influence on the integrity, composition and mechanical properties of the resultant welds. The work outlined in this paper is one of several welding programmes currently in progress at N.C.R.E., and full acknowledgement must be given to the assistance of colleagues and the stimulus of their helpful criticism.

Welding Processes

With each increase in the size of ships' hulls, and especially in the thickness of the steel plate used, the problems of economics and of availability of trained manpower have forced more and more attention onto automatic methods of welding. The well-known manual welder with his "stick" electrode, who can be found in most workshops, deposits only one or two lb. of weld metal per hour, after making allowances for time which is lost in a variety of essential but subsidiary operations. Fully automatic processes exist which can deposit from 10 to 100 lb. of weld metal per hour. Not all of these are at present suitable for use in shipbuilding, but one which has been much used in mild steel construction is the submerged-arc process.

The principles involved in the submerged arc welding process are shown in outline in Fig. 1, and in closer detail in Figs. 2(a) and (b). The consumable wire electrode is (usually) a plain bare wire typically of $\frac{1}{8}$ in. diameter, and is drawn off from a 10 - 50 lb. reel mounted on the welding machine. A layer of flux approximately 1 in. deep is supplied to the job via the feed tube immediately in front of the welding head, and after welding the fused flux (slag) is removed from the welded joint and discarded.

The flux is a granular material resembling table sugar as regards the size and shape of particles, and its many functions form the basis of this paper. The primary function, however, is to protect the hot weld region by excluding air. Samples of flux are shown in Fig. 3.

The productivity of the process is high, but the notch toughness of the weld metal produced is frequently below that obtained in welds of the same strength made manually. This is a general observation which has been made on other occasions in respect of other steels[1], and is in no way specific to welds in Q.T.35. Some improvement in weld metal toughness may be obtained, at the cost of productivity, by restricting the amount of weld metal deposited in a given run and demanding that more, smaller runs be made to fill a given weld joint, but some preliminary laboratory experiments showed that in Q.T.35, even at the same size of weld run, the toughness of the submerged arc weld was still inferior to that of the welds made using the manual electrode Fortrex B, which for some years has been approved for use with Q.T.35.

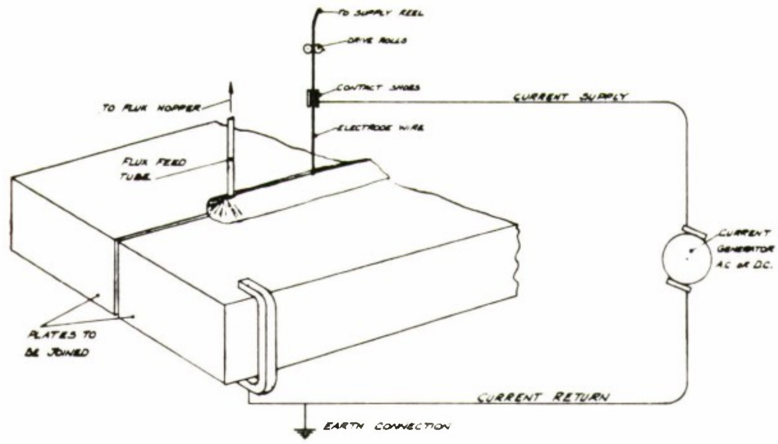


FIG. 1. Typical arrangement for machine welding under flux cover.

There was therefore felt to be a need for work on the notch toughness of submerged arc welds in Q.T.35, to investigate the cause of poor notch toughness relative to manual welds, and if possible to effect improvements.

Reactions During Submerged-arc Welding

In submerged-arc welding the initial function of the wire is to provide one electrode of the arc, the other being the workpiece. The arc melts some of the workpiece and all of the wire, and arc forces divide the molten wire material into a spray of fine drops. The adjacent flux also melts, and some of the molten flux forms an intimate coating around the metal droplets as they transfer into the weld pool. There the flux material is supposed to float out and leave a clean pool of molten weld metal which later solidifies to give a high-quality weld joint. Under given cooling conditions the mechanical properties of the weld depend upon its chemical composition, and this depends largely upon the composition of the wire used in the first place.

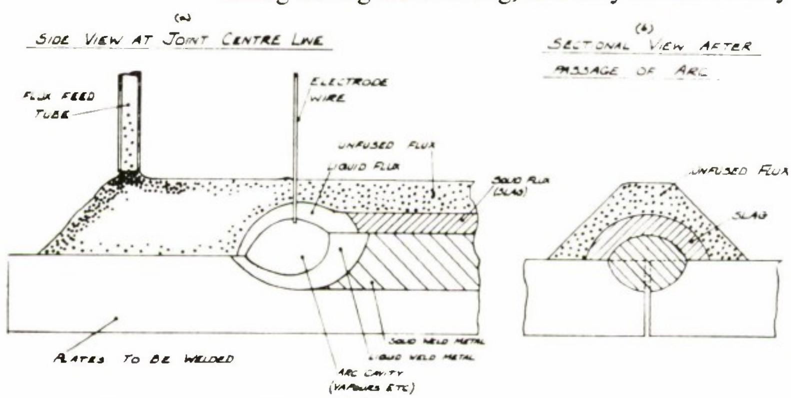


FIG. 2. Details of submerged arc welding.

At the high temperatures obtaining within and beneath the arc there is sufficient energy available for complex chemical reactions to take place between the flux (slag) phase and the metal phase, the most important of which are the solution and leaching-out of alloying elements (the direction of movement and whether it is harmful or beneficial depending upon the element and the circumstances of the case) and the oxidation-reduction reactions which for the welding of steel are of the type $Fe + MeR \rightleftharpoons Me + FeR$ where MeR represents a compound of the metallic element Me with an oxide or similar radical, R.

The course of the above reactions has been much studied under the relatively sluggish conditions prevailing during steelmaking, and they are now fairly

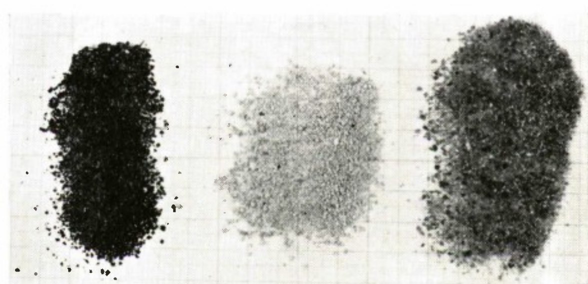


FIG. 3. Samples of submerged arc welding fluxes—Left—Lincoln P1, Right—B.O.C.G.80, Centre—N.C.R.E. improved flux.

well understood, so much so that they are constantly being used in steelmaking for the purification or deliberate alloying of the steel. During the welding operation, on the other hand, the whole sequence of heating and cooling is over in a matter of seconds, so there has been little opportunity for basic research on the reactions which occur. Despite this there have been many empirical attempts to use the welding flux as a vehicle for alloying elements to give the weld deposit a boost in alloy content, and hence strength, over that of the material of the wire itself. The size of the increase, however, varies with a number of factors such as the actual voltage and the effective temperature of the arc, and with the relative quantities of flux and wire consumed per unit length of weld. Experience has shown that during actual welding the situation cannot be controlled with sufficient accuracy. It is therefore considered better practice to use fluxes of neutral alloy content.

Fluxes of neutral alloy content are not, however, necessarily inert. The melting-point (strictly, the liquidus-solidus interval) of the flux has to be close to that of the metal, so that the solid slag can give mechanical support, and control of profile, to the weld metal as it in turn solidifies. For the welding of steels the melting-point requirement can only really be met by the use of a mixture of metallic *oxides*. On grounds of the law of mass action alone, therefore, the oxidation of some of the excess iron becomes a distinct possibility:—

$$Fe + MeO \rightarrow Me + FeO$$

The flux containing a potentially reactive oxide must be regarded as alloy-bearing. The problems outlined in the previous paragraph therefore still apply, with the added complication that the oxygen involved in the reaction could be detrimental to the toughness of the weld.

If the composition of a flux can be discovered it is possible in principle to pick out the reactive oxides by the use of tables of standard thermodynamic data, and to relate these metallic oxides to the metallic elements which other work has shown to affect the toughness of steel plate. For example silicon is harmful but manganese is beneficial to the toughness of steel plate[(2)], and both SiO_2 and MnO are potentially reactive with iron[(3)]. These two oxides can and do react with iron in a different welding situation[(4)]. Are they present in submerged-arc welding fluxes ?

In the European and American welding world it is very difficult, even for customers of long standing, to discover the compositions of commercially produced fluxes. Only in Soviet researches are the compositions of fluxes regularly and openly quoted in published literature, but occasionally they are also quoted in the Japanese literature. Sufficient information was eventually gathered to confirm that MnO and SiO_2 were sometimes present in large quantities in fluxes for the welding of steels. Was this true of the fluxes being used for Q.T.28 and Q.T.35 ?

COMMERCIAL FLUXES

Samples of more than a dozen fluxes in everyday use in Britain were taken and analysed at Bragg Laboratory, Sheffield. The results are quoted in full in reference[(5)]. No flux had less than 35% SiO_2 by weight, and some contained as much as 55%. The MnO contents ranged from nil to 50%. The other common constituent was CaO (up to 25%), with significant quantities of MgO and Al_2O_3 (10 - 20%) in some of the fluxes. Most of the fluxes were neutral in terms of metallic alloy content, but some contained significant amounts of nickel.

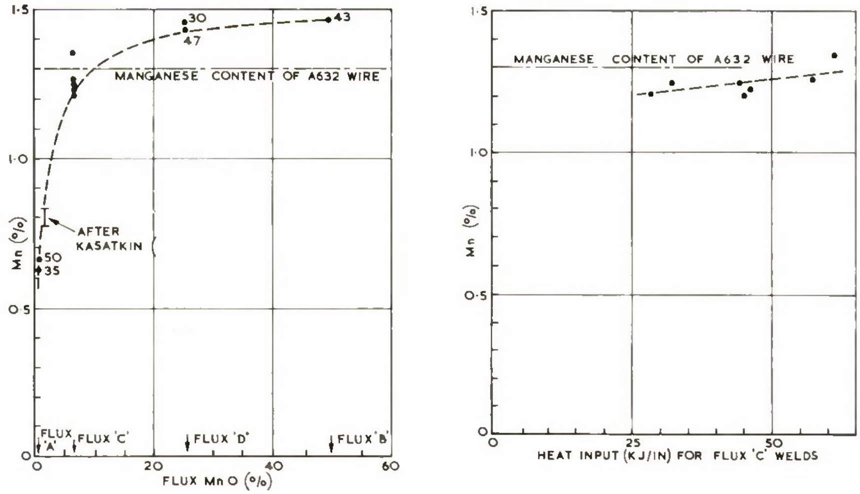
A series of four commercial fluxes were chosen, having similar SiO_2 contents (40 - 50%) and a wide range of MnO contents (0·1, 7, 26, and 50%). The 26% MnO flux also contained 2% Ni. The 7% MnO flux happened to be G8O, the flux currently approved for Q.T.35.

Using as a constant reference the high-quality alloyed welding wire known as A.632 (see Table 1), submerged-arc welds were made, using a standard preheat of 130°C, in Q.T.35 plate. The actual thickness of 1½ in. was determined, in this case as in these referred to below, solely by considerations of experimental convenience. The heat input during welding was varied by changing travel speed in the range 10 to 20 inches per minute, and to extend the range of heat input two different wire sizes were used (1/16 in. and 3/32 in.

TABLE 1. Typical Compositions of Q.T.35 Plate and A.632 Wire (Wt%)

	C	Mn	Si	P	S	Ni	Cr	Mo	V
Q.T.35	0·12	1·2	0·3	0·03	0·03	1·2	1·0	0·5	0·1
A.632	0·07	1·3	0·5	0·01	0·01	1·2	0·1	0·4	0·1

FIG. 4.
Mn content of welds made using commercial fluxes of various MnO contents.
Numbers on points refer to weld heat input in thousands of Joules per inch.



diameter). The voltage during welding (measured between the contact shoe and the return-current clamp) was approximately 30V, and the machine current was set to 200A and 390A for the 1/16 in. and 3/32 in. wires respectively. Direct current was used for welding, the wire being the positive electrode. This polarity was used throughout the present work. The highest heat input was a calculated 61 Kilojoules per inch (KJ/in.) and the lowest was 28 KJ/in.

Radiography confirmed that the welds made were satisfactory. The slag and the weld metal were analysed, and the tensile and impact properties of the weld metals produced were determined.

The tensile strength of the weld metals obtained for the three non-alloyed fluxes was 40 - 45 t.s.i. yield, and did not differ significantly from one flux to another (a constant composition of wire had been used), but the Ni-bearing flux gave a weld which was significantly stronger, and this corresponded with an actual increase in the Ni content of the weld. Changes in heat input were not associated with any obvious change in tensile strength, but when the data for the non-alloyed flux G8O were analysed by least squares the slope calculated was $-0{\cdot}20 \pm 0{\cdot}08$ t.s.i. per KJ/in.

The impact strength of the various welds varied widely with the flux used. The Charpy V-notch test, and also the Pellini drop-weight test, showed that even the best impact performance was inferior to that obtained using Fortrex B.

Investigation of weld metal compositions, and comparison with the composition of the corresponding fluxes and slags, showed that the weld metal Mn content could be higher or lower than that of the wire (Fig. 4). Wide variations in weld metal Si content also occurred. These observations confirmed qualitatively that the reactions anticipated by analogy with steelmaking experience in fact occurred under conditions of submerged-arc welding. For a given flux no significant variation in weld metal composition with heat input (*i.e.* travel speed *i.e.* time before solidification) was detected, suggesting further that even in the short times available a virtually complete equilibrium of composition was attained.

Poor values of impact performance were associated with the occurrence of significant increases in weld metal Si or Mn, and with simultaneous increases in the content of weld metal oxygen and of slag FeO. The best impact values were obtained with G8O flux, which had shown the smallest movements of Mn, rather than with the high MnO fluxes which had shown a positive gain of Mn in the weld metal. It appeared that the reduction of the MnO and of the SiO_2 by the mechanism outlined above was a direct cause of the poor impact performance, and SiO_2 in fluxes was believed to be especially harmful, for the reasons mentioned earlier.

EXPERIMENTAL FLUXES MADE AT N.C.R.E.

It was felt worthwhile to investigate the weld metal properties obtainable using fluxes in which the SiO_2 content was reduced or rendered harmless

(i) by increase in the proportion of basic oxides to reduce the effective availability (activity) of SiO_2, or

(ii) by substitution of amphoteric or acidic oxides which were less reactive in terms of free energy.

Procedure

Approaches to commercial flux manufacturers having failed to arouse any response, a method was developed at N.C.R.E. Metallurgical Laboratory by which experimental compositions of flux could be made in small (nominal 10 lb.) batches. Check analyses confirmed that the fluxes produced were completely satisfactory as regards purity and accuracy of composition, and other tests (described later) confirmed that melting-point and particle-size range were suitable. The method of flux manufacture by fusion and subsequent fritting is fully described in reference[6].

A total of 50 experimental fluxes were made, divided roughly equally into three main series.

(i) Lime-silica-fluorspar mixtures, representing an extension of other attempts[7] to improve weld metal properties by progressively increasing flux basicity,

(ii) Lime-silica-alumina mixtures, representing an attempt to eliminate the acidic SiO_2 from the fluxes and to substitute the amphoteric Al_2O_3,

(iii) Lime-silica-titania mixtures, representing an attempt to substitute for the reactive acid oxide SiO_2 the less-reactive but still acidic oxide TiO_2,

and a miscellaneous group for confirmatory tests on some published American and Soviet flux compositions. Also the opportunity was taken of studying the effects of deliberately altering the composition of a commercial flux. Full details of the flux formulae are given in reference[6].

Each batch of flux was just sufficient for two plain-butt welds 12 in. long in $\frac{3}{4}$ in. thick Q.T.35 plate. Approximately 10 and 8 runs were needed to fill the single-V weld preparation at the chosen heat inputs of 35 and 50 KJ/in. respectively. All the A.632 wire used in this part of the work was of a single size (3/32 in.) and was obtained from a single heat of steel, thus ensuring the highest constancy possible in composition.

After welding every joint was radiographed. Sets of Charpy impact specimens and pairs of Hounsfield tensile specimens were prepared when the weld was suitable, and were tested in the as-laid condition. Weldmetal and slag analyses were again performed.

Lime-silica-fluorspar Fluxes

Commercial fluxes containing CaO and SiO_2 have a basicity ($CaO : SiO_2$ ratio) of less than unity, consequently a CaF_2 content of 5 - 10% is sufficient to ensure a suitable melting-point. With this CaF_2 content a series of experimental fluxes covering the basicity range from below 1 : 1 to above 3 : 1 were prepared, with the idea that progressive increases in basicity should lead to decreases in weld metal sulphur, phosphorus and silicon[7]. Analysis revealed the expected variation in silicon, but sulphur and phosphorus, although satisfactorily low, were not seen to decrease as expected. The weld metal impact strength however did increase with increasing flux basicity, the best being better than that obtained with the best of the commercial fluxes referred to above, and being also as good as that obtained with Fortrex B. The tensile strength was similar to that obtained with the non-alloyed commercial fluxes.

There was a slight but progressively increasing tendency to weld metal porosity in the first-series fluxes as basicity values rose above unity and melting point rose. In a second series of fluxes the CaF_2 content was increased to 20% to reduce melting points, and it was found that despite increasing basicity the onset of porosity was much delayed. In a third series of fluxes the CaF_2 content was raised to 50% but there then was an increased incidence of porosity. The exact cause could not be ascertained, but from a partial reconstruction of the appropriate region of the $CaO\text{-}SiO_2\text{-}CaF_2$ ternary diagram (Fig. 5) it would seem that the melting-point had been reduced too far.

In a separate series of fluxes MnO was added (up to 15%) in a highly basic flux. The weld metal properties were poor but the compositions obtained (Fig. 6) gave a direct confirmation of the trend found earlier (Fig. 4) with commercial, acid fluxes.

Lime-silica-alumina Fluxes

The actual flux compositions were based on eutectics of melting points between 1300° and 1400°C[8] selected so that two were of $CaO : SiO_2$ ratio close to unity and two were substantially free of SiO_2, being composed mainly of CaO and Al_2O_3. Progressive additions of CaF_2 and MnO were also made. The welds as a whole were radiographically satisfactory, and tensile strengths were as for the $CaO\text{-}SiO_2\text{-}CaF_2$ fluxes. The impact strengths were no better than the values obtained using the commercial fluxes.

Lime-silica-titania Fluxes

These were based on the extensive central area of solid solution around the equimolecular sphene composition $CaO.SiO_2.TiO_2$, in which melting points range from 1320°C to 1380°C. Progressive additions of CaF_2 were also made. The majority of the welds were radiographically good, and tensile strengths were as before. The impact values were generally good, being comparable with or better than those obtained using the commercial fluxes, and the best were better than is obtained using Fortrex B.

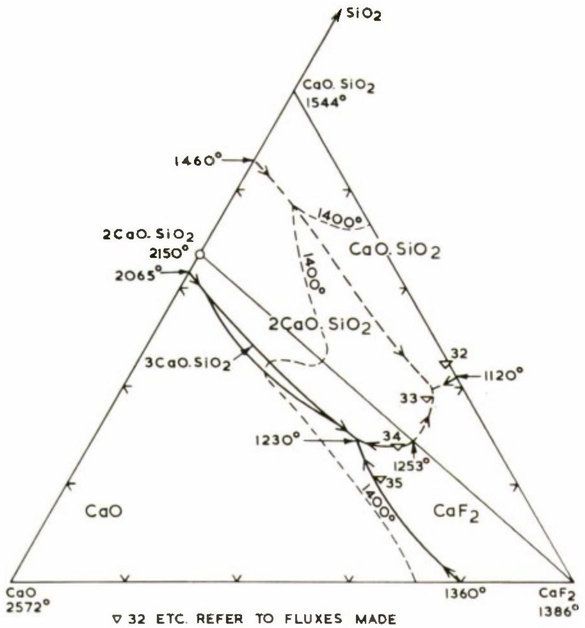


FIG. 5. Partial phase diagram of ternary system CaO-SiO_2-CaF_2, reconstructed from published data (8) Temperature in °C.

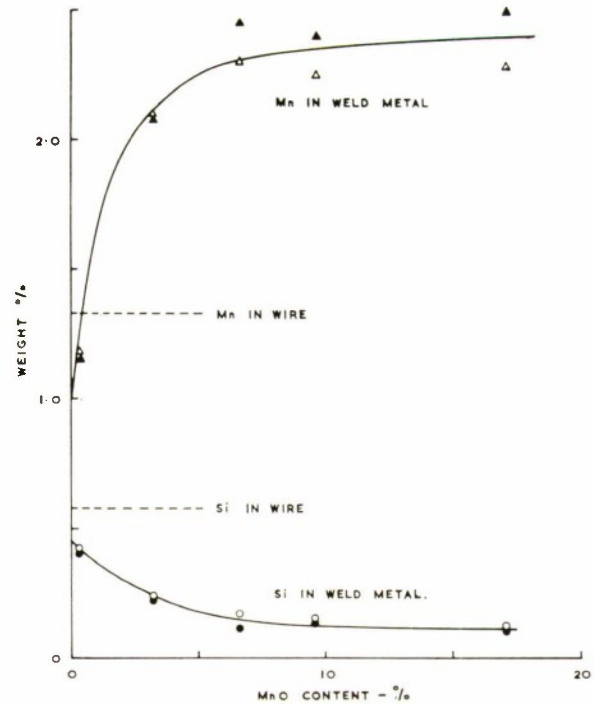


FIG. 6. Mn and Si contents of welds made using experimental fluxes of various MnO contents. Heat inputs as shown.

Miscellaneous Fluxes

A comparison with three American fluxes was made by copying the published formulae[1]. The impact values ranged from fair to good, but where comparison with the U.S. data was possible the agreement was remarkably close.

Five Soviet fluxes were similarly remade. Using simply the published formulae fluxes were produced which performed highly satisfactorily. The impact strengths obtained were only fair, but were what would be expected from the nature of the fluxes as revealed by the published formulae.

In industrial practice submerged-arc welding is frequently performed in the presence of rust and scale. Some fluxes are reputedly tolerant of such misuse. One such was the commercial 50% MnO flux previously examined. Samples of this flux were re-melted with progressively increasing amounts of FeO (up to 20%). At the highest FeO content there was a slight increase in the incidence of weld porosity, but the weld metal properties were poor throughout the series.

Application

Several lines of flux work had by this time been investigated, admittedly on only a very small scale, but of these two lines (CaO-SiO_2-CaF_2 and CaO-SiO_2-TiO_2 ranges) had appeared sufficiently promising to justify further study. In order to enlarge the scale of testing, either multiple batches had to be made within N.C.R.E., or commercial manufacturers had to be interested in what was virtually pilot-plant work. Both approaches were tried, the latter being preferred as it was more realistic. Sooner or later the fluxes would have to be manufactured on an industrial scale and would then require to be assessed as industrial products.

Inquiries were made with all the British welding suppliers, and with several Continental firms, and two firms undertook work. Both are wholly British, one being a nationally known company with interests in all aspects of gas and electric welding, and the other being a small firm (Metrode Ltd., of Weybridge, Surrey) of which the main business at the time was the manufacture of tailor-made manual electrodes for specialised applications. Work with the larger firm is still under way. With the smaller firm substantial progress has been made on both types of flux, but especially on the CaO-SiO_2-CaF_2 range of fluxes.

EXPERIMENTAL FLUXES MADE COMMERCIALLY

The smaller firm was asked to make fluxes of three specified compositions 1, 2 and 3 (basicity values 1·6, 2·1 and 2·6) within the general range:— CaO 45-55%, SiO_2 20-30% and CaF_2 10-20%, with additions of 5% TiO_2 and 2% Na_2O for arc stability. This exercise was repeated for three separate deliveries. The various 50 lb. lots of flux

were identified by a laboratory convention whereby say, the number 203 represented the second delivery of the composition No. 3.

The method of flux manufacture used (agglomeration, which is a room-temperature process akin to the balling-up of concrete when the dry materials are first wetted in the revolving drum) was completely different from that which had been used at N.C.R.E., and several confirmatory experiments were therefore needed simply to evaluate the effects of the different method of production. No serious effects were in fact found, and it was possible to go on to relatively large-scale welding tests.

Main Welding Tests

Chemical analysis of the first fluxes 101-3 having shown them to be satisfactory, two welds 3 ft. long were made using each flux. Q.T.35 1¼ in. thick was used, with a double-V weld edge preparation and 130°C preheat. Heat inputs used were 35 and 50 KJ/in. Three of the welds were completely clear radiographically and the other three showed isolated defects which were not serious enough to interrupt in any way the manufacture of test specimens.

Six welds were similarly made using the 201-3 fluxes, with similarly good radiographic results, and the same pattern was repeated with the 301-3 fluxes. Tests are continuing on further batches of the fluxes.

The weld metal tensile strengths were again mostly in the range 40-45 t.s.i. yield stress, but slight systematic variations with heat input were detected. These will be discussed later.

The weld metal impact properties were highly satisfactory, and compared well with what is obtained using Fortrex B. Figs. 7 (a-e) show the Charpy results for the 15 welds, superimposed on the scatter band (interquartile range) for a series of 16 welds made using Fortrex B. The Pellini drop-weight test results were also satisfactory, confirming that for all practical purposes the fluxes as made industrially were consistent from batch to batch and that they reproduced the performance obtained using another method of production in another place.

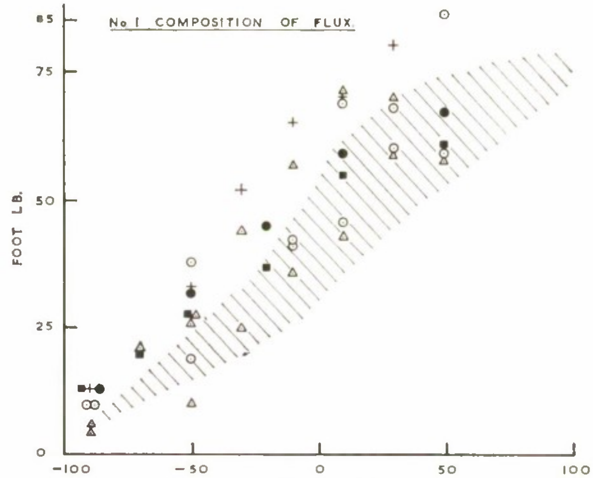


FIG. 7 (*a*).

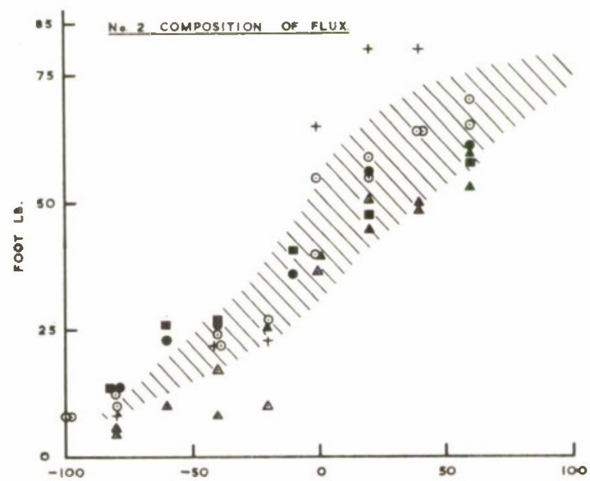


FIG. 7 (b).

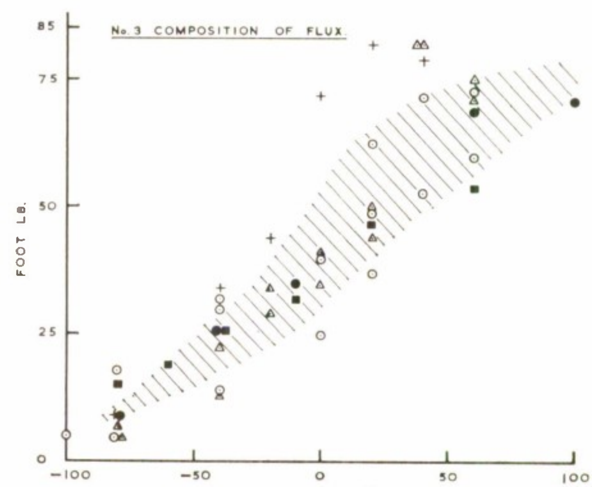


FIG. 7 (c).

LEGEND.

HEAT INPUT KJ/IN.	35	50	70	90
FIRST BATCH	△	⊙		
SECOND BATCH		●	■	
THIRD BATCH				+
INTERQUARTILE RANGE FOR FORTREX 'B'			⑊⑊⑊	

FIG. 7. (a) (b) and (c) The consistency of performance for various batches of respectively, the No. 1, 2 and 3 flux compositions produced commercially—Charpy—V energy values obtained from submerged arc welds made using A632 wire, compared with those of Fortrex B welds.

The other major property of the wire-flux combination which needed to be assessed was the tendency to introduce impurities, and for these to segregate in the solidifying weld metal, with the result that the weld cracks under the inevitable stresses of contraction. This problem is particularly acute in the root run of welds, where unfortunately it is the most expensive to repair.

Several factors are responsible, but the basic one is that the root run weld, perhaps only $\frac{1}{4}$ in. thick, is asked to bear all the contraction stresses arising in a plate which may be considerably thicker. Fig. 8 shows the kind of cracks which can form. Several methods of weld testing are known, but none of these was suitable for the present type of welding programme, so it was necessary to rediscover and adapt a test which was originally described in 1946 but later fell into disuse(2). Fig. 9 gives a general view of the N.C.R.E. test piece, showing a failed weld.

Tests in Q.T.35 steel up to $2\frac{1}{4}$ in. thick were unable to show any obvious difference between the experimental fluxes and the commercial fluxes P1 and G80 which are approved for use with Q.T.28 and Q.T.35. Even after extensive testing only marginal differences were found, but such differences as existed favoured the experimental rather than the commercial fluxes.

	Flux	*Tests made*	*Cracking found*
Series A	301	42	7
	G80	42	10
Series B	302	54	8
	G80	54	16

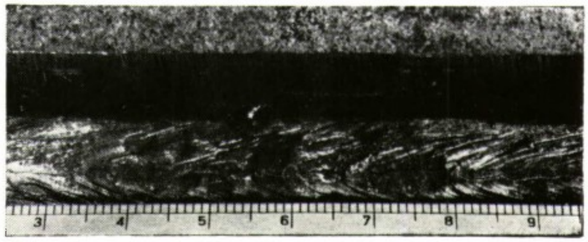


FIG. 8 (a). Example of cracking in the root run of weld. Surface view.

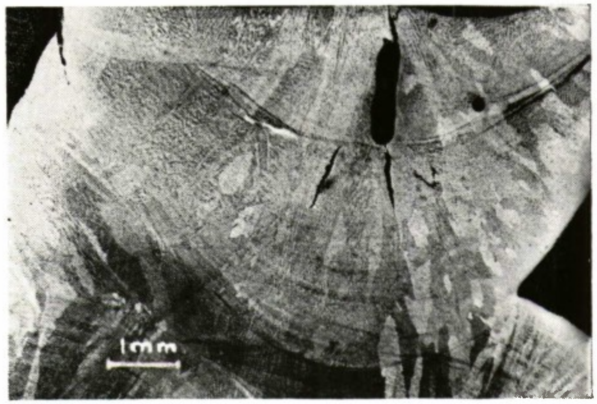


FIG. 8 (b). Example of cracking in the root run of weld. Sectional view.

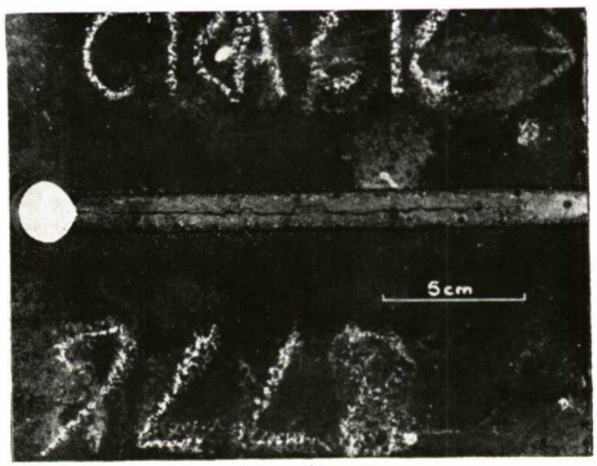


FIG. 9. Specimen for weld cracking test.

Other Tests

Experience of fluxes in actual welding situations suggests that many details of the properties and performance of a new welding flux ought to be investigated in the laboratory before the flux goes into general use. Such details include the shape of the weld bead produced, and the ease and completeness of slag removal after welding (with which the relative melting-ranges and other properties at high temperatures are intimately concerned), the ease of moisture removal from the flux by baking, its density, the particle size distribution and even the ease with which the powder flows. All of these were checked, the comparison in most cases being against the commercial fluxes G.80 and P1.

Examination of the surface appearance and sectioned slices of weld runs laid on flat plates and in actual V-shape weld edge preparations confirmed that the general shape of the welds was as with commercial fluxes. The N.C.R.E.-made Soviet flux compositions were outstanding in the excellence of weld appearance, but the majority of the N.C.R.E. fluxes gave a good appearance. When however, they were made by agglomeration the weld surface was frankly rough, with deep and irregularly spaced ripples and hollows. The corresponding slag bead was sponge-like and fragile, suggesting the evolution of a gas while the slag was in a pasty state. The slag was not self-lifting (as are G80 and P1) but it was easier to remove than the slag produced by Fortrex B. The systematic radiography of welds confirmed

that the slags could in fact be removed virtually completely, as otherwise there would have been recorded a much larger incidence of defects where one weld run had bridged-over the slag left by an earlier run.

The significance of flux melting-range in relation to that of the material being welded has already been mentioned. Measurements were made on both commercial and experimental fluxes and their slags, using in one case an optical pyrometer sighted onto slag samples in a tube furnace, and in the other by observing the fusing down of flux samples in furnace boats or in the form of compressed free standing cylinders in a muffle furnace. Both the experimental and the commercial fluxes melted over short ranges (say 50°C) between 1200°C and 1400°C.

The importance of moisture in a welding flux or in an electrode coating is that in the arc it breaks down and releases highly mobile hydrogen atoms and/or ions, of which some diffuse *via* the weld pool into the plate adjacent to the weld but (strictly) outside the weld itself. Contraction and metallurgical retransformation stresses on cooling, together with this hydrogen, can induce what is known as heat-affected zone cracking. Ideally there should be no moisture present at all, but a reasonable practical limit is 0·2 gm H_2O per 100 gm of flux or coating material. The N.C.R.E.-made fluxes had been fused into glass-like crystals which were virtually impervious to moisture. Even after quenching in water a simple bake at 250°C reduced the moisture content to less than 0·02%. The agglomerated fluxes had been bound using waterglass (sodium-potassium-silicate) which holds water in chemical combination up to red heat. Nevertheless a bake of 400°C was sufficient to reduce a grossly exposed sample of flux to a moisture level of 0·13%, which compares satisfactorily with the figure of 0·17% when Fortrex B electrodes are similarly treated.

The bulk density of the granular fluxes is obviously important as regards transport, storage and the capacity of hoppers on machines, but it also has a bearing upon the pressure which a given height of flux overburden (Fig. 2(a)) exerts at the weld surface and hence, together with the ease of flow, upon the tendency of the flux to fall-in upon the weld and give it full protection from the atmosphere at all times. The actual density of the fused flux material, compared with that of the molten weld metal, is believed to have an influence on the buoyancy of the flux while mixed with metal in the weld pool, and hence on the extent of slag trapping. The bulk density of the fluxes was measured by filling a container of defined volume with the flux and then weighing. The actual density of flux particles was assessed by

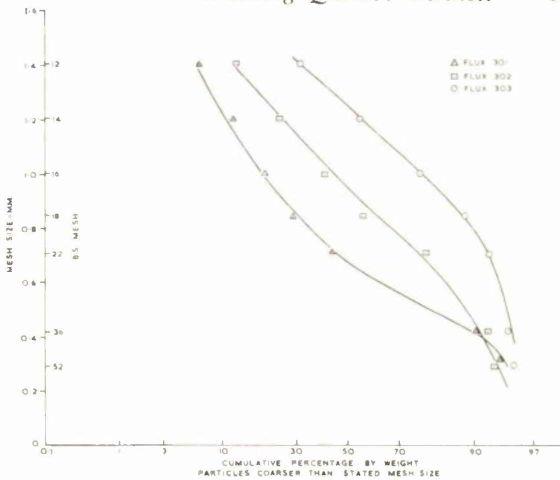


FIG. 10. Size distribution (cumulative) for experimental agglomerated fluxes 301, 302, 303.

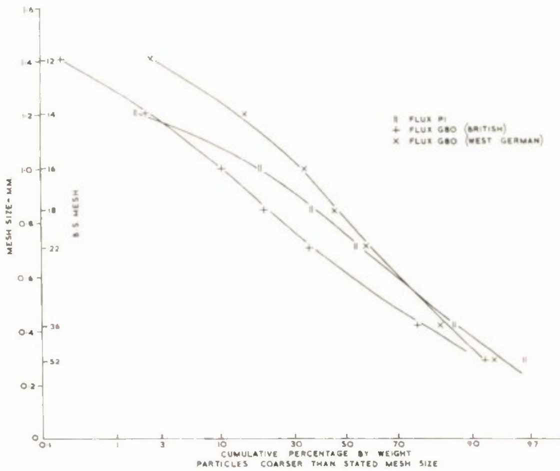


FIG. 11. Size distribution (cumulative) for commercial fused fluxes P1 and G8O.

observing, by displacement of water, the actual volume of a previously weighed sample. The bulk density of the commercial fluxes ranged from 1·0 to 1·7 gm/cc, the fused fluxes having the higher bulk densities and the agglomerated fluxes being less dense. The experimental fluxes 301-3 gave low values of bulk density (0·9 to 1·0 gm/cc) but the actual density was 2·5 gm/cc. The actual density of the commercial fluxes was slightly higher (3·0 to 3·5 gm/cc).

The basic reason for studying the flow of granular fluxes has been mentioned above, but as the jamming of a supply hose has high nuisance value there existed a practical interest also. A wide range of commercial and experimental fluxes were placed in a ranking order by the simple test of timing the flow under gravity of a standard volume of flux through a standard orifice, namely the 3 mm diameter throat of an ordinary laboratory

funnel. The flow characteristics of agglomerated fluxes in general were slightly inferior to those of fused fluxes (probably reflecting the lower bulk densities of agglomerated fluxes), but the experimental agglomerated fluxes 301-3 gave values closely similar to those of commercial fluxes also produced by agglomeration.

The particle-size distribution was determined by the use of a mechanical vibrator with a bank of British Standard sieves. Results, expressed as the cumulative percentage (probability function) of particles coarser than a given mesh size, are shown in Figs. 10 and 11 for the fluxes 301-3 and for G80 and P1.

DISCUSSION

General

Two main advantages to Navy Department have come out of the present work. One is the obvious fact that a programme of research and development has led to the actual production of welding fluxes giving superior properties to those obtained with the fluxes previously available. The new fluxes will need a name. In view of their origin within N.C.R.E. the eponymous ENCREX would seem appropriate.

The other advantage is that having done this work once there now exists a framework of knowledge of flux formulation, preparation, testing and use, all of which has been fully documented, which can be turned to similar problems if the need should arise in the future. In particular, it is now possible to obtain analyses of a given wire/flux combination and, using the criteria which have been outlined, to comment on the general suitability of the products. This procedure should reduce considerably the time taken and the effort involved in preliminary screening prior to formal approval testing.

Previously such knowledge of fluxes as existed was the jealously-guarded preserve of a very small number of individuals scattered about the welding industry, working (one suspects) largely by hunch. Now that it has been demonstrated that viable fluxes can be made in one country to formulae established in another, a situation arises similar to that in the rest of metallurgy, where co-operative study and open publication on compositions, properties and techniques have led to deepening understanding and useful advances of great value to manufacturer and user alike.

Weld Appearance

The rough surface appearance of the welds made with the experimental agglomerated flux has been mentioned earlier. This was not found to be particularly serious in practice, but a few experiments were conducted in the laboratory in an attempt to ease the position. The porous nature of the slag was probably a direct result of the flux composition chosen, and little could be done about this, but the deep ripples on the surface of the solid weld were thought to point to fluctuations in the arc forces while the weld pool was on the point of solidifying.

In the first place it was argued that in the agglomerated flux sodium and potassium silicates had been introduced during the binding operation, and it was possible that they would be found preferentially in one particle-size range rather than another. As Na and K are very readily ionized their presence in one particular size-range might stabilize the arc and so reduce the extent of rippling. A sample of 302 flux was taken and divided into four similar-sized fractions by sieving. Bead-on-plate weld runs were made using the size fractions of flux under identical welding conditions but no significant changes were found.

It was then argued that perhaps the welding voltage had been set at an unstable value, but no improvement was found when this was altered over a 15% range.

Finally it was argued that as calcium carbonate is used in formulating manual electrode coatings, which then " burn " under the heat of the arc to produce calcium oxide, perhaps the carbonate had also been used by the present flux manufacturer. Inquiry confirmed that this was so. By roasting the flux at a temperature in excess of 916°C any $CaCO_3$ present would be broken down to CaO and CO_2. When weld beads were laid using 302 flux which had been roasted, and were compared with beads laid under the same conditions but using 302 flux which had merely been baked to expel moisture, a distinct improvement was seen (Fig. 12). Quantitative analysis of the gases produced when a later flux of No. 2 composition was roasted in this way showed that per cc of flux approximately 85 cc of CO_2 was released, a figure which compares satisfactorily with the figure predicted from consideration of the actual amounts of minerals (wollastonite and ground marble in particular) used in preparing a flux of a given basicity value.

When the roasted-flux and the dried-flux weld beads were sectioned and examined it was found that the roasted-flux bead showed a much deeper penetration into the baseplate and, in spite of the bead being narrower, planimetry of photographic enlargements showed that a significantly larger amount of metal had been melted. The flux in which the $CaCO_3$ had *already* been broken down was apparently the *less* efficient at converting electrical energy into molten metal. It would seem that CO_2 in the arc region is a positive aid to thermal efficiency.

FIG. 12. The effect of flux roasting on weld bead appearance.

Weld Composition

At the start of the present work it was surmised that the oxidation-reactions

$$MnO + Fe \rightarrow Mn + FeO$$
$$\text{and } SiO_2 + 2Fe \rightarrow Si + 2FeO$$

are reversible under the conditions of time and temperature appropriate to submerged-arc welding. That this is true is well illustrated by the data of Fig. 6 obtained on a series of N.C.R.E.-made fluxes in which the proportion of MnO was progressively increased in a flux basis which was of otherwise constant composition. The weld metal Si is seen to be slightly below that of the A632 wire at low levels of slag MnO, and falls progressively as MnO content increases. The weld metal Mn is slightly below that of the wire initially, but with increasing MnO content soon rises to above that of the wire. At the highest MnO contents studied the weld metal Si and Mn figures appear to level off at values of, respectively, about 0·5% below and 1% above those in the wire. The significance of these numerical values will be discussed below.

The fact that the weld metal Si and Mn are both influenced by changes in the level of flux MnO content, and that they appear to reach saturation values at similar levels of flux MnO, is taken to imply that the two reactions interact with each other *via* the FeO which is common to them both, and furthermore that the effective weld pool temperature is such that the free energy changes in the two reactions are similar, and therefore that at weld temperatures the oxidation-reduction reactions of Si and Mn are reversible and occur simultaneously, reacting with one another. To quote an example, the reduction of a given amount of MnO to Mn produces a corresponding quantity of FeO, which then drives the Si reaction in the reverse direction, so that a corresponding quantity of the elemental Si is oxidised. In terms of chemical equivalents a gain or loss of 55 gm of elemental Mn is associated with the movement of 16 gm of oxygen, which is associated with respectively a loss or gain of 14 gm of elemental Si.

The fall in Si (or Mn) content between the starting and the final compositions could be described as plain deoxidation. However, for the present argument it is more useful to think of the oxygen as being taken up by the Si (or Mn). Correspondingly the reduction of an oxide, leading to an increase in the appropriate element, is seen in the present context as the liberation of oxygen. It must be appreciated that no gaseous molecular oxygen is actually evolved: some of the oxygen is probably taken into solution but the majority is combined again into another oxide, probably FeO. The important feature of the argument is that the amounts of oxygen liberated or taken up can readily be calculated from available data*, and the amounts so calculated should *prima facie* be equal.

On going through the calculations for the saturation values shown in Fig. 6, per 100 gm of weld metal the Si fall represents an oxygen uptake of 0·51 ± 0·05 gm, and the Mn rise represents the liberation of 0·31 ± 0·02 gm of oxygen. The errors assigned are compounded from the probable limits of accuracy in chemical analysis and from observation of scatter in the data. The difference is statistically significant (0·20 ± 0·06 gm per 100 gm) and represents a net uptake of oxygen.

It is not precisely known where the oxygen comes from. Calculating the oxygen-difference for the different welds made under different fused fluxes a net uptake of 0·2 - 0·3 gm per 100 gm is found in virtually all cases. The size and constancy of the uptake rule out the possibility of effects due to moisture, or to traces of other unstable oxides in the flux. The effect of other active deoxidants in the wire, or in the flux, would be to reduce the losses found in the known deoxidants, and hence to reduce the apparent size of the oxygen uptake. The gross entrainment of air must be rejected, as no corresponding increase in weld metal nitrogen has been found. By a process of elimination one is left with the hypothesis of rapid and selective diffusion of atmospheric oxygen through the supposedly protective slag layer, which it will be recalled is composed mainly of oxides.

* A fall, for example, of 0·28% Si i.e. 0·28 gm Si per 100 gm weld metal, is equivalent to the formation of $0{\cdot}128 \times (28 + 2.16)/28 = 0{\cdot}60$ gm SiO_2, i.e. the uptake of 0·32 gm oxygen per 100 gm weld metal, as revealed by the Si fall alone. A similar calculation may be performed on the basis of observed changes in Mn content.

The difficulty with this hypothesis is that using the experimental agglomerated fluxes the apparent oxygen uptake is increased when by the breakdown of $CaCO_3$ large volumes of CO_2 are generated in the heated flux around the weld position. The oxygen figure then found is 0·5 gm per 100 gm, and this is apparently unchanged by the operation of roasting the flux to remove CO_2.

Work on the oxygen anomaly is continuing, both for its intrinsic interest and for its practical relevance. High-strength steels are becoming more complex and more precise in their alloying, and welds in them must follow suit. It is significant that already difficulties have been reported in the submerged-arc welding of steels containing easily-oxidised stabilisers such as boron in austenitic steel and titanium in maraging steel.

A different aspect of weld composition, but one which is particularly relevant to its impact properties, is the control over sulphur and phosphorus which from considerations of steelmaking practice a basic flux should be expected to provide. That some control had been provided by the fluxes was shown by noting the different levels of S and P in welds made under different types of flux, otherwise using the same wire and the same welding conditions. Where full data on the composition of wire, flux, slag and weld metal were available it was possible to work out the actual desulphurizing power of a given flux used in a welding situation, and to compare this with the ratio predicted for a flux of that type used under steelmaking conditions. The correlation was decidedly poor. In view of the practical importance of S and P in welding this anomaly is being investigated further.

Weld Properties

The tensile strengths obtained in welds laid with A.632 wire using a wide variety of flux types have been fairly consistent at 40-45 t.s.i. yield and 45-50 t.s.i. ultimate. It would appear that compared with the choice of wire the choice of flux has only a second-order effect upon composition and hence upon strength. The actual strength levels obtained so far slightly overmatch what is needed for Q.T.35, but they would be well suited to a Q.T.42.

On the other hand, very wide variations in impact toughness have been found, for welds laid using different types of flux. The movement of Si and Mn previously discussed can account for some of the variation, but there is much fundamental work still to do.

Turning to the XO1-3 fluxes, it can be seen from Fig. 7 (in spite of the obvious scatter) that the best impact values were found at the highest heat input studied, which was 90 KJ/in. This trend has been confirmed in a separate series of welds made over a wide range of heat inputs (from 35 KJ/in. up to 350 KJ/in.). Above about 100 KJ/in., however, the impact values fell again, the difference between best and worst being a factor two. This pronounced dependence of toughness on heat input for a given wire-flux combination was not associated with any detectable change in composition, but there was a slight (3-4 t.s.i. in 40 t.s.i.) inverse variation of the weld metal yield stress. Below 100 KJ/in. also, the higher the heat input the lower was the yield stress.

Checking back over the welds laid using the N.C.R.E.-made fluxes, to see whether similar effects could be found, it was possible in a number of cases to compare the yield stress values obtained, using a given flux, at the two heat inputs of 35 and 50 KJ/in. Grouping the values of Y(50) - Y(35) according to the kind of flux used, for the alumina fluxes the mean was $-3{\cdot}0$ t.s.i., with a standard error on the mean of $\pm 0{\cdot}40$ t.s.i. For the sphene fluxes the result was $-2{\cdot}2 \pm 1{\cdot}5$ t.s.i. These values are the same within the limits of error, and remarkably close also to the slope calculated earlier for the G80 welds. To check whether A.632 wire itself was the cause of this effect, or whether it was a special feature of submerged arc welds, a further series of welds were made using A.632 wire as before, but with a proprietary gas mixture as the shielding medium. The welds were then lower in strength, but the dependence of strength on heat input was found yet again:—

Heat input 35 KJ/in.,
mean yield stress $39{\cdot}9 \pm 0{\cdot}4$ t.s.i.
heat input 50 KJ/in.,
mean yield stress $38{\cdot}5 \pm 1{\cdot}0$ t.s.i.
heat input 75 KJ/in.,
mean yield stress $35{\cdot}2 \pm 0{\cdot}3$ t.s.i.

The common factor throughout has been the use of A.632 wire.

The practical implication of this is that for A.632 wire, and possibly for others as well, it is necessary so to choose the heat input that the optimum combination of weld metal strength and toughness is obtained. It is fortunate in this case that the highest toughness is found at a level of heat input which is an improvement, in terms of productivity and also in terms of toughness, over the situation in manual welding using Fortrex B.

Conclusions

A significant improvement over commercial fluxes for the welding of QT.35 has been achieved by original research within N.C.R.E. A body of organised knowledge now exists which is available for similar problems in the future.

Using the improved fluxes welds of fair to good surface appearance can be obtained, and in all important respects the improved fluxes are as convenient to use as are the commercial fluxes at present used with Q.T.28 and Q.T.35.

The chemical composition of the welds is influenced significantly by the choice of flux, but not to any obvious extent by the level of heat input used. Chemical reactions between metal and flux do occur, and can in certain circumstances be harmful. Some, but not all, of these reactions seem to reach equilibrium in the limited time available during welding.

The impact toughness of welds using A.632 wire has been found to vary widely, depending on flux type and heat input. The tensile strength has been found to vary similarly but to a less marked extent.

Acknowledgement

The work has depended at all stages on chemical analyses performed by Bragg Laboratory, Sheffield. It is a pleasure to acknowledge the help given.

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NEW ASSAULT SHIP COMMISSIONS

H.M.S. *Intrepid*, commissioned on Saturday March 11th, at the Clydebank yard of John Brown, under the command of Captain J. A. R. Troup, D.S.C.*, R.N.

The ship has been designed to enable a military force to land its heaviest armour, transport and equipment, under operational conditions, on any coast. A Royal Marines Commando or infantry battalion, may be carried in air conditioned accommodation to the scene of the operations; the whole Force being put ashore by landing craft, hovercraft and/or helicopters. The floating dock principle is used to allow the larger landing craft to float out of the stern of the ship.

The amphibious beach unit, including R.N., R.M., and Army personnel, controls the beach side of the operation, while the landing and development of the force ashore is controlled from a combined operations room. Communications can be established so that the Force Commander may talk to his Naval counterparts, to ensure joint control of the landing.

The vehicle docks, where the tanks, vehicles and stores are stowed, are supervised by a Captain in the Royal Corps of Transport. The Flight Deck can operate all types of helicopters carrying troops and supplies.

The supply Department, in addition to its normal task of supplying the needs of 590 officers and men of the R.N., R.M., and Army, must also support the varying needs of up to 700 embarked marines and soldiers.

The ship's main machinery is steam turbine. Ballasting machinery for flooding the dock and operating the stern gate, is an unusual addition to the engineer's responsibilities.

The ship's armament consists of four Seacat guided missiles and two Bofors mounting.

H.M.S. *Intrepid*, with her ability to land a highly trained military force virtually anywhere in the world, at high speed and with great economy, is a most versatile and powerful newcomer to the Fleet.

H.M.S. *Intrepid* has a displacement of 12,000 tons, a length of 520 feet and a beam of 80 feet.

S.E.R.L.
Argon Ion
laser and holograms

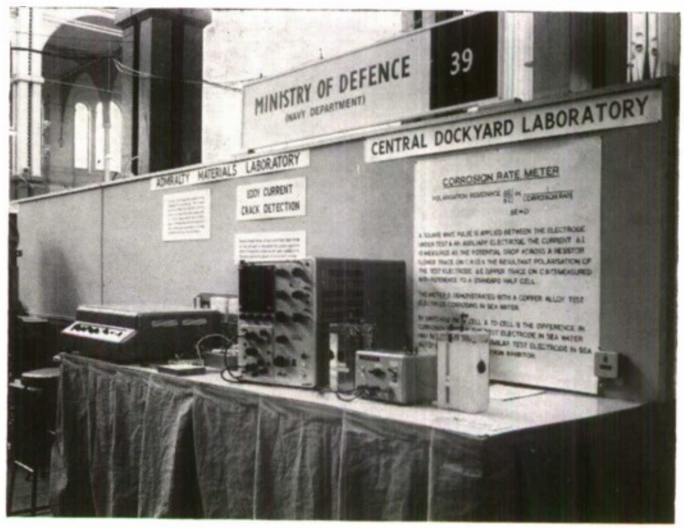
A.E.W. Compensated Conductivity waveprobe.

NAVAL EXHIBITS AT THE

A.S.W.E.
Electronically steered
radar aerial.

S.E.R.L.
Thermal conductivity of Beryllia
IKW travelling wave tube and
Gunn effect microwave oscillator.

PHYSICS EXHIBITION 1967



A.M.L.
Eddy current crack detector.
C.D.L.
corrosion rate meter.

A.S.W.E.
Coaxial cable tester.

Notes and News

Admiralty Engineering Laboratory

A great deal of interest was centred on the Admiralty Engineering Laboratory's contribution to the Royal Navy's Stand at the 1967 International Engineering and Marine Exhibition. A working model of an Automatic Starting and Protection System for Diesel Generator Sets was demonstrated using some of the latest techniques in the use of fluid logic devices.

Work on a complete system, of which the demonstration showed only a small section is presently being progressed jointly by the Admiralty Engineering Laboratory and the Plessey Automation Group to provide the Royal Navy with possibly its first application of fluid logic control.

Fluid logic or fluidic techniques have many distinct advantages over other methods of equipping prime-movers with automatic starting and protection systems. The ability to withstand extreme shock, vibration and temperature conditions added to the reliability provided by non-moving part devices make them attractive for Naval applications.

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Admiralty Surface Weapons Establishment

Captain N. E. F. Dalrymple-Hamilton, C.V.O., M.B.E., D.S.C., R.N. relieved Captain A. A. T. Seymour-Haydon as the Captain at A.S.W.E. as of January 13th, 1967. Immediately preceding his appointment to A.S.W.E., Captain Dalrymple-Hamilton held the post of Director of Naval Signals at the Ministry of Defence.

On 2nd March, 1967 the Directors of the Ship and Weapons Departments held the latest of their "Schweppes" series of meetings at A.S.W.E. The day began with a series of short lectures by members of the establishment's staff and these were followed by general discussion on such matters as ships of the future. During the afternoon, the visitors were shown representative examples of the establishment's current work which were particularly relevant to the discussions. Other recent visitors to A.S.W.E. have included: Vice-Admiral H. R. Law, the Controller of the Navy; Mr. R. Mason, Minister of Defence (Equipment); Captain A. F. Caswell, R.N., Director of Weapon Programmes; and Herr K. Freiberg, the German Embassy Attaché for Defence Research and Development.

Mr. E. J. Walsh, Senior Experimental Officer, retired from the service on Friday, 31st March, 1967, after nearly 45 years' service. Miss E. Killick read a paper on Radar Techniques to the members of the Portsmouth and District Physical Society at their meeting at the College of Technology on 8th March, 1967.

Admiralty Underwater Weapons Establishment

On 25th February, Mr. John Drury retired after fifty years of continuous Admiralty service.

He joined the Royal Navy as an Artificer Apprentice in 1917 and finally retired as a Chief Engineroom Artificer in 1945 when he joined the A/S Establishment at Fairlie as a Mechanical Draughtsman.

He was promoted to Leading Draughtsman four years later and to Senior Draughtsman in 1952. When he reached retirement age in 1966 he elected to continue to serve in a disestablished capacity for a further year.

During his Drawing Office career, John Drury was a prominent and extremely active member of the Admiralty Draughtsmen's Association and Society of Technical Civil Servants.

The photograph shows him being presented with a cheque contributed to by his D.O. colleagues, by Mr. S. H. Bowie (left) the Drawing Office Manager at A.U.W.E.

A.U.W.E. was among the local employers who participated in a Careers Convention at Weymouth organised by the Dorset County Council Youth Employment Service in collaboration with All Saints Secondary School, Weymouth. The convention lasted one day. In the morning the stands were open to viewing by children aged 14 and upwards from schools in Weymouth and the surrounding area; in the afternoon, talks were given to senior children at All Saints School on careers open to them locally—(130 opted to hear about A.U.W.E.!); in the evening, the Convention was open to parents who wanted advice or information on careers.

In addition to having a stand at the Convention—a first venture in this field since the formation of A.U.W.E. —two live ' exhibits ' were arranged. One of our tracers was engaged in making an actual tracing and a teleprinter was available for the children to try their hand at, under the charge of an A.E.O.; this " do-it-yourself " feature proved a great draw.

A series of leaflets was prepared in an attractive format (by A.U.W.E's Reproduction Section) giving details of careers open to school-leavers: craft apprentice, scientific assistant, tracer, typist, photoprinter, machine or duplicator operator, and clerical staff.

The stand included as a centrepiece a model of H.M.S. *Leander,* kindly lent by D.G.S., and showed typical work by craft apprentices and laboratory mechanics. Credit for this is due principally to Mr. Longley (recently transferred from S.E.R.L. on promotion to Chief Artificer), Mr. Sandford (foreman pattern maker and joiner) and Mr. Harris (Principal Photographer).

Central Dockyard Laboratory

Mr. J. Smith attended the meeting of the International Organisation for Standardisation (ISO/TC 35/SC9) " General Methods of Test and Sampling for Paints and Varnishes " in London on 15th, 16th and 17th of February, 1967 and was Chairman of the associated working parties on " Resistance to Humidity " and "Accelerated Weathering " on 13th and 14th February respectively.

Royal Navy's Second Nuclear Dockyard

Chatham is to become the Royal Navy's second nuclear dockyard for the servicing of nuclear-powered Fleet submarines.

On March 1st, 1967, Mrs. John Parker, wife of the Admiral Superintendent (Rear Admiral W. J. Parker, C.B., O.B.E., D.S.C), laid the foundation stone of a ten-storey accommodation and office block forming part of a £4 million development programme.

The administrative office and new accommodation block is one of the group of buildings on a compact site between two existing dry docks, selected to permit concurrent servicing of two Fleet submarines. It will be dominated by a large cantilever crane which has both docks within its radius of action.

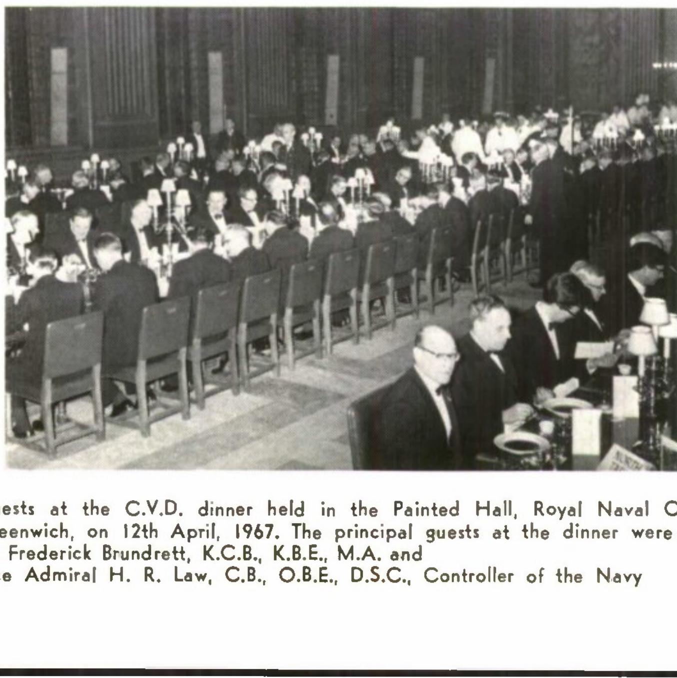
A number of highly specialised buildings are planned including a refuelling equipment ship providing facilities for the preparatory work necessary for the delicate operation of refuelling. The strictest control of personnel and equipment will be maintained.

As announced in November the Royal Navy has six nuclear-powered Fleet submarines in service, building or planned. The precise rate at which it is intended to continue to build Fleet submarines has not yet been decided.

R.N. Orders Two More Frigates

The Royal Navy has ordered the construction of two more Leander Class frigates, the 23rd and 24th of the Class.

Following a successful competitive tender, the order has been won by Messrs. Yarrow & Co. Ltd., of Scotstoun. The main machinery will be provided by Messrs. J. Samuel White & Co. Ltd., of Southampton.



Guests at the C.V.D. dinner held in the Painted Hall, Royal Naval College, Greenwich, on 12th April, 1967. The principal guests at the dinner were Sir Frederick Brundrett, K.C.B., K.B.E., M.A. and Vice Admiral H. R. Law, C.B., O.B.E., D.S.C., Controller of the Navy

Book Reviews

Radio Wave Propagation V.H.F. and Above. By P. A. Mathews, pp. 155. London; Chapman & Hall Ltd. 1965. Price 28s.

This is a small book about a fairly large subject, namely the propagation of radio waves at frequencies above those at which the ionosphere acts as a reflector. It is intended as an introduction to the study of radio propagation for graduate students, but it could obviously be of wider use since no comparable book at this level exists. The breadth of coverage can be seen from a recitation of some of the topics which are dealt with: Line-of-sight propagation, atmospheric refractive index profiles and ducting, atmospheric attenuation, diffraction by the earth and obstacles, tropospheric scatter, system loss on transmission circuits, propagation by scattering from the ionosphere and meteor trails, atmospheric noise, and applications to communications and radar. Most of the information on these matters resides in technical journals so the attempt this book makes to cover the field is a praiseworthy one.

The danger of compressing a lot of subject matter into a few pages is that the text can become so condensed or superficial that one has to know something about the subject to make any sense of it. From this point of view this book is not uniformly successful. Examples of the less illuminating parts are the treatments of tropospheric scatter and back scatter from the sea. With such a broad canvas an uneveness of treatment is understandable if not actually excusable. What is much less understandable are the large number of misprints, errors and loose statements. For example, there are serious errors in the equations derived in the geometrical treatment of tropospheric refraction, and the statement that at v.l.f. " the wavelength may be several thousand kilometres and the earth's diameter only a few wavelengths " is out by two orders of magnitude. The statement that the polar diagram of an aerial is " the Fourier transform of the cosine of amplitude distribution " will raise the eyebrows of those who know better and confuse those who don't. There is a somewhat cavalier attitude to decibels —it is not always stated that power levels with respect to some standard level are in fact measured in db, field strength is on one occasion measured in μv/metre when it should be db above 1 μv/metre (p. 134), and one meets such statements as " the reflection coefficient . . . . may be expected to vary from the coherent value of -50 db to an incoherent value of twice this or -100 db." There are quite a few more examples than these and nearly all reflect a surprising carelessness and looseness of thought on the part of the author. Most are merely irritating but some could misinform and waste the time of the reader.

It is a pity that the book suffers from these faults, for in spite of them it still contains a great deal of useful information for its size. Although the reader should be forewarned of its shortcomings, it nevertheless represents good value for its modest price and should be a useful acquisition for those working in radar, communications and related fields who have an interest in propagation.

E. R. Billam

Introduction to Transistor Electronics. By R. L. Walker. Pp. ix + 341. London; Blackie & Son Ltd. 1966. Price 27s. 6d. Pb; 50s. Bnd.

At first sight this work appears to be just another addition to the long line of books under similar titles and covering similar subject matter. The material presented by the author does indeed follow the general pattern, dealing firstly with semiconductor physics, proceeding to mathematical treatment of the transistor and then onto circuit models and equivalent circuit analysis. From these chapters is developed the theory of low and high frequency amplifiers and concluding with a treatment of switching and logic circuits.

There are two major differences between this and previous books on the subject, the first is that the text is very readable and comprehensive and the second is that it really is an introduction and a very good one. As a textbook for the student on his first venture into transistor electronics, this work is invaluable as it indeed may be to the established practising engineer or scientist who may wish to be in the picture as far as modern semiconductor devices and techniques are concerned.

The first 90 pages of the book admirably cover the fields of semiconductor electronics in a comprehensive manner, particularly the basic theory, junctions and an excellent chapter on the mathematical treatment of the transistor which relates physical phenomena to the mathematical theory.

The usual treatment of the equivalent circuit approach for the different transistor configurations is presented but with a unique insight into the topic such that the reader does not contract a feeling of detachment from the actual circuits as usually is the case when dealing with matrix analysis.

The next five chapters provide a notable coverage of such subject matter as characteristic curves, power amplifiers, high frequency circuits, cascade and feedback amplifiers, and video and bandpass amplifiers. The pole-zero concept is used in support of some of this theory without attempts to explain this concept and some readers may find this approach misleading due to unfamiliarity, but this will not deter the majority of students.

There then follows a chapter introducing more recent developments such as the drift transistor, field-effect transistor and tunnel diodes.

A short chapter on Switching Circuits, which is excellently written, precedes the final chapter on Logic Circuits wherein Boolean Algebra, simple Logic circuits, and worst-case design methods are discussed.

All chapters are concluded with a list of pertinent references and a few test problems earmarking this work as an excellent teaching textbook in addition to being a first class learning textbook.

Perhaps one of the most superficially remarkable factors is its astonishingly modest price at only 27s. 6d. in a sturdy paper back form (50s. bound) and this work could proudly take its place at the head of previous works along this theme.

D. Robson

Applied Electricity, 4th edition. By A. W. Hirst. Pp. xiii + 439; London; Blackie & Son Ltd., 1966. Prices 55s. (cloth). 35s. (paper).

The author has without a doubt done what he has set out to do, that is, he has produced a textbook which is to be highly recommended to first year university students reading for a first degree in electrical or electronic engineering. Although he has very carefully followed the syllabus set by the Senate of the University of London, the material covered will more than satisfy the first year requirements of the other universities throughout the country together with the requirements of the various

Engineering Institutions. The subject dealt with is of course "Applied Electricity" which covers the field of: d.c. machines, single phase a.c. theory, the transformer, three phase circuit theory, a.c. machines, a.c./d.c. conversion, transmission and distribution of power, illumination, instruments and measurements.

Each topic is treated with the clear understanding that first year students are somewhat limited in mathematical ability and consequently the reader is introduced to the physics of the subject and not made to labour through endless (often pointless) mathematics. Second year students will also find parts of this book—especially with regard to a.c. machines—very useful to them. The author has been very thorough in his explanation of the basic principles underlying "Applied Electricity" and each chapter leaves one with the feeling of having been guided by a very able man. By introducing a.c. quantities in terms of vectors rather than by direct application of the " j " operator, the author has well prepared the reader for later work on the transformer and a.c. machines. The chapter on measuring instruments is written in a most attractive way with a wide variety of instruments and measuring techniques being reviewed, simple equations being derived for each instrument. The table of electrical and mechanical units showing how each quantity is defined and how its dimensions in terms of " length, mass, time and current " are derived, will help considerably students who have any difficulties with dimensional analysis of electrical quantities. Electrical engineering materials, often excluded from textbooks of this kind, are given a short informative chapter to themselves. The only criticism which can be raised lies in the author's explanation of the production of the " rotating field " in a three phase induction motor, in that it is not obvious that there is a rotating magnetic field. Had the author made more use of vectors (as he had in other sections) then the overall picture might have been clearer.

This book is attractively presented and printed, the diagrams are clear and the type pleasant to read. The author is to be congratulated for writing an excellent textbook which will find itself on many students' bookshelves.

D. J. Mackinnon

Microwave Valves. By C. H. Dix and W. H. Aldous. Pp. 275. London; Iliffe Books Ltd., 1966. Price 55s.

Nowadays new books on active devices are usually concerned with solid state structures. However, the valve still holds a pre-eminent place in the microwave bands and an up-to-date book reviewing and presenting the principles of operation of current devices in this field is to be welcomed. The authors have not attempted to write an advanced text but have obviously aimed their work at those engineers of graduate and H.N.C. level who have not yet acquired a background in the subject, Thus, the mathematical treatment is kept to a minimum and much of the work is descriptive, whilst imparting adequately the sort of information upon the features, parameters, advantages and shortcomings of various types of microwave valves which is required by the engineer working upon the design of microwave systems, without delving into the finer points of valve design.

The short first chapter might well have been omitted, since the readership aimed at should be familiar with the more elementary concepts of such subjects as the structure of matter, the acceleration of electrons in an electric field and the energy stored in magnetic and electric fields. After this, the text settles at a reasonable level when dealing with the motion of electrons in steady fields, the properties of distributed r.f. circuits and waves on electron beams. A somewhat curious inclusion is a chapter upon low and medium frequency valves, which can only be partly justified by its leading on to the microwave operation of thermionic diodes. Most of the book is devoted to beam and cross-field valves, i.e. helix-type and high power t.w.t's, klystrons, magnetrons and the amplitron. In the last chapter of the book, headed " Noise," parametric amplifiers and masers are briefly mentioned. It might perhaps be suggested that the authors should have broadened their own terms of reference, to include more upon these, but since this would imply the consideration of solid state devices, it could have led on to acoustic waves in solids, Gunn effect, PIN diodes and all other aspects of the incursion of solid-state devices into the microwave field, with consequent increase in size (and price) of the book.

The style is noteworthily clear, with good explanatory diagrams. Chapter bibliographies are included, but cover textbooks only, no original papers being mentioned. The authors have dealt only with existing devices and have made no attempt to predict possible future trends. Within these limits they have succeeded in writing a good introductory text reviewing the field.

R. J. Male

Modern Electronic Components. By G. W. A. Dummer. Pp. viii +516. London; Sir Isaac Pitman & Sons Ltd., 1966. Price 63s.

Mr. Dummer states, in the preface to this book, that the British electronics components industry is currently producing seven million components a day. It is therefore surprising that so few books have been written on this subject and Mr. Dummer's book attempts to fill an obvious gap in current technical literature.

'Modern Electronic Components' contains thirty-three chapters which can be conveniently divided into three groups. The first of these comprises four chapters dealing with such topics as specifications, colour codes and conventional symbols. These chapters form a valuable introduction to the remainder of the book although a considerable amount of space is wasted, for example in a four page table listing in detail the colour combinations used to designate every possible resistor value.

The major part of the book comprises thirteen chapters, each one dealing with a specific type of component, for example resistors, capacitors, switches and batteries. The scope of these chapters can be illustrated by considering, as a typical chapter, that dealing with fixed capacitors.

The chapter entitled 'Fixed Capacitors' begins with a brief discussion of the various dielectric media which are used in capacitors and includes notes on insulation resistance, dielectric strength and frequency effects. In subsequent sections these notes are amplified into a discussion of the various types of capacitor which are available. The chapter concludes with a useful bibliography containing over eighty references.

The last fifteen chapters of the book cover a wide range of miscellaneous topics and make a useful and interesting conclusion. Topics covered include operation in tropical and Arctic climates, the effect of vibration on components and the long term stability and failure of electronic components.

'Modern Electronic Components' is one of the few books in its field and thus will be of considerable value to those whose work involves the use of electronic components. In some ways, however, it is disappointing. Several times the impression is given that material is included or displayed to fill space. One example of this has been given and other examples occur in the illustrations: in particular, a three-quarter page illustration of

a film winding machine is so trivial that it is worthless. Another criticism concerns the bibliographies: these are, in general, useful but contain few references later than 1960. Despite these criticisms 'Modern Electronic Components' is a valuable introductory survey of a neglected field.

C. H. Gooch

Kingzett's Chemical Encyclopaedia. Pp. xi + 1092. London; Baillière, Tindall & Cassell, 9th Edition, 1966. Price 150s.

A chemical encyclopaedia which has, for 47 years, held the position of a standard reference book, is obviously a fairly monumental work. It also represents a monumental task for anyone attempting to review such a volume. Nearly 1200 pages, 15 distinguished contributors drawn from all parts of the U.K. and U.S.A., and some 4500 separate entries related to a booming and rapidly developing subject make it necessary to have almost as many reviewers as contributors. Kingzett's has, however, a sub-title which states that it is "a digest of chemistry and its industrial applications"—the number of chemical substances is already so vast that it would be impossible even to list them all in one volume, so that a selection chosen for inclusion must be made on the basis of providing the maximum knowledge required by the maximum number in the best possible form.

The encyclopaedia is not therefore intended to serve the specialist in his own field, and its primary aim is to be of assistance to virtually anyone else whose work brings him into contact with chemistry, chemical processes, and raw materials of all kinds.

With this at the back of his mind, the reviewer applied the test of investigating a random selection of materials and elements familiar to him in order to check for (a) inclusion and (b) accuracy. It must be admitted that he found it difficult to fault the volume on the first point, although at first sight he thought this should have been relatively easy with something that started at "abietic acid" and finished with "zwitterion"! Some 10% in number of the total entries in the volume were used as a test, and only a very small percentage of the test samples were found not to be in the book. The samples ranged from materials encountered in the nuclear field, viz., uranium, plutonium, thorium, hafnium, strontium, beryllium, samarium, gadolinium etc., to terminology such as roentgens, rads, reps and rems, from electron spin resonance to reactors and activation analysis, and from enzymes, chromosomes and blood counts to radiation hazards. About 80% of all items tested could be readily found in the book, either in the main text, or through the index (which gave alternative names of all subjects, but not main entries already given in the text). One could find such unlikely things as "condensed milk" nestling alongside a fungicide known as "Milban"; one could find something on "pumps", but not on "cyclones", on steam, heat, and horsepower, but not on humidity, or corrosion, but not on cementation, on thermocouples, but not on constantan, and so on, but in general the volume lived well up to its avowed aims. Some of the definitions and explanations were, probably necessarily so, fairly limited and crude, e.g., on steam, on atomic power production and on reactors; some did not give properties the reviewer would have considered important, viz.—no nuclear properties were given for zirconium and hafnium, and nothing was said of the toxicity of beryllium. On the other hand, the important subjects were given adequate references to provide for follow-up reading. In the medical field, whilst the reviewer has only a nodding acquaintance with medicine, and then only in radiation medicine and biology, it appeared to him that a generous coverage of pharmaceutics was given.

Few diagrams are included and there are a limited number of graphs, but there seemed to be an adequate number of well laid out and easily followed tables. Printing is good and it is a very easy volume to use.

The encyclopaedia then, fully lives up to the preface by the General Editor, Professor D. H. Hey, Head of the Department of Chemistry at Kings College, London, and also to the original concept of its founder, the late C. T. Kingzett, to provide a digest of chemistry and its industrial applications in a form which would be useful as a work of reference to the whole community. The reviewer found it of great interest and utility, and with a firm recommendation that all who can afford it should at once invest in it, concludes with a real admiration of the work of all who participated in the production of this ninth edition of "Kingzett's Chemical Encyclopaedia."

J. Edwards

The Dynamics of Linear and Non-Linear Systems. By P. Naslin. Pp. xxvii + 586. London; Blackie & Son Ltd., 1965. Price 105s.

Somebody once said that originality was the ability to remember what you have read but forget where you read it. Whether that is true or not, this book is certainly original. Its approach is unusual and it contains ideas and methods which are not to be found in other textbooks. Colonel Pierre Naslin has been an expert on Automatic Control with the French Corps of Armaments since the war and has written many papers and articles on the subject. This work is his own translation of one originally published in France in 1962.

The first chapter is on block diagrams and signal flow graphs, and concludes with an exposition and proof of Mason's formula. This formula enables you to write down the transfer function relating two variables in a multi input and output block diagram almost by inspection. The next chapter, on transients, does not use Laplace transforms but employs a "p operator" similar to Heaviside's. Here, as in what follows, several examples are fully worked out in the text. Immediately after this an E transform is introduced. E is a delay operator which at once provides a numerical solution to transient problems and at the same time prepares the reader for the discussion of sampled data systems later on. The E transform can be derived direct from the p transform of the impulse or step response and the graph of the transient drawn from it.

The section on frequency response is conventional with an interesting discussion on non-minimum phase networks. A useful chart is provided to simplify the addition of frequency response loci without recourse to roundabout methods using M contours on the Nichols chart. There follows a discussion of the relationship between transient and frequency responses. Methods are given for obtaining the transient graph from the frequency locus, the frequency locus from the transient, and the expression for the transfer function from either.

Next the Routh-Hurwitz, stability criterion, Leonhard's damping criterion and the Nyquist criterion are covered. The difficulty of obtaining an algebraic criterion, which tells you the degree of damping, instead of just stating whether the system is stable or not, is emphasised, and the author then unfolds his own damping criterion for characteristic equations of order higher than two. The method is based on standard polynomials with a constant relation between their coefficients. Formulae are given for the response time and percentage overshoot of the standard polynomials, and tolerances are provided, which give the allowable departure of the coefficients from those of the standard polynomials without appreciably changing the stability characteristics.

The method, further developed, has recently been described in an article in "Control."

After this comes the chapter on sampled data systems, and then the subject changes to non-linear systems. The describing function is used to cover forced oscillations as well as stability, and the dual input describing function explains away subharmonics and related topics. The method of isoclines is applied to non-linearities proper in the phase plane, and then a larger section on piecewise linear systems deals with relays, backlash and optimal switching.

The final chapter presents very clearly two methods of computation, one numerical and one graphical, which are simple to use and can be applied to a large number of linear and non-linear problems.

The text is unfortunately marred by a number of misprints in the formulae, and its meaning is sometimes obscure, because, no doubt, English is not the author's mother tongue. However such defects are unimportant when compared with the interest of the subject matter, and the book is highly recommended. Its concentration on numerical methods will make it useful to users of digital computers, and the author's claim that he has lead the reader as directly as possible to the solution of real problems is justified.

A. P. R. Wippell

Understanding Graphs. By S. A. Knight. Pp. viii + 231. Glasgow; Blackie & Son Limited, 1966. Price 18s.

This book sets out to present a "full and general survey of elementary graphical mathematics." In this it succeeds; no previous knowledge seems to be assumed in Chapter 1 and the last three chapters deal with trigonometric functions, maxima and minima and polar co-ordinates. Concrete examples and exercises abound. This is a commendable effort since, as the author points out, this important subject is often dealt with very sketchily. However, the length and price seem excessive. The style is chatty and prolix. I should have thought that this ground could have been covered satisfactorily in much less space.

H. N. V. Temperley

Standard Statistical Calculations. By P. G. Moore and D. E. Edwards. Pp. xi + 115. London; Sir Isaac Pitman & Sons Ltd. 1965. Price 27s. 6d.

Every year sees fresh books on Statistics appearing in publishers' lists and one is apt to regard newcomers with a somewhat wary eye, as to whether their publication is necessary or not. However, it can be said that no one textbook satisfies everybody's demands, and the authors of the book under review can be said to have established a case for its existence.

The book first came to life as a statistics manual for internal use in the Reed Paper Group. This group employs a large statistics department, and the manual was written, more by way of an expedient than anything else, i.e. to speed up the work of the more junior staff. Prompted by the success of internal use of their manual, the authors have published it in the hope that it could be used as a handbook for practical classes associated with courses in statistics. Their hope has been largely justified.

The contents of the book faithfully reflect the title, "Standard Statistical Calculations." The calculations are tailored to suit the use of electrical desk calculating machines, but such machines are not essential in actually carrying out the various computations, although a small manual machine would eliminate some of the tedium in the more complicated cases.

The book consists entirely of worked illustrative examples, covering those statistical methods most frequently used in practice:— Tests for means, analysis of variance, correlation and regression, multiple and quadratic regression, analysis of frequencies, analysis of ranked data, fitting of distributions, and tables of the normal, t, χ^2 and F distributions. Each calculation is treated in the same way:— Object, Method, Example. In the section on method, reference is made to one of four books on Statistical Theory, indicating where the relevant theory of the particular example may be found.

Exercises for the student are given at the end of each chapter and answers to these are provided at the end of the book.

For those who are content with how to do it as opposed to why, then this book is a very useful tool. For those who wish to understand the theoretical basis for the methods employed, then this book may well be considered to be inadequate, as mere reference to further books entails having additional sources within easy reach. Nevertheless, for the operational research worker who already knows his basic statistical theory, this book can find a very worthy place on his personal bookshelf.

W. E. Silver

Some Contemporary Studies in Marine Science. Ed. H. Barnes. Pp. 716. London; George Allen and Unwin Ltd. 1966. Price 147s.

This volume is a "Festschrift" presented to Dr. Sheina M. Marshall, O.B.E., F.R.S. by her colleagues and friends on her retirement after over 40 years on the staff of the Marine Station, Millport. With Dr. Marshall in the dedication is linked the name of the late Dr. A. P. Orr also of that laboratory and her life-long collaborator. As is proper, the contributions reflect primarily the interests of the recipient and there is a large number of papers dealing with planktological problems. In the course of a long working life not all of one's colleagues continue in the same field and in their subject matter a number of contributions reflect this wider interest among her scientific colleagues.

There are 50 separate papers in this book, varying greatly in size and content, in this reflecting the difficulty inherent in producing such a volume. Not all the potential authors will have had major length papers sufficiently advanced to be included. Contributions in consequence range in length from three pages to some forty pages. A rough separation of the papers by subject, rough because many could be assigned to any one of several categories, gives the following breakdown: planktology 13, physiology and biochemistry 13, zoology 10, botany 5, benthic ecology 7 and marine chemistry 2. To mention only a few topics there are papers on plankton production and volume (Williams, Vanucci), biochemistry of zooplankton (Raymont *et al*), zooplankton biology and systematics (Edwards, Matthews, Mauchline, Pearce), feeding of Copepods (Adams and Steele, Conover, Gauld) evolution (Millar) and seaweeds (Kanwisher, Powell). Thus there is plenty to satisfy the biological oceanographer but little for the oceanographic chemist and still less for the physicist.

Of more particular interest to the applied marine biologist in the field of ship-fouling are three papers dealing with barnacles. Bainbridge and Roskell redescribe the larval stages of *Lepas fascicularis*, first described by von Willemöes-Suhm in 1876, and also consider the occurrence of *Lepas* nauplii in the N.E. Atlantic on the basis of Plankton Recorder surveys. Barnes and Barnes record in some detail the occurrence of the common shore barnacles on the west coast of Europe from

northern France to Gibraltar. Barnes and Powell consider the distribution of *B. balanoides* and *Elminius modestus* together with that of the seaweed *Fucus serratus* and the winkle *Littorina littoralis* at Arcachon, France, an area at the southern limit of distribution of these northern species. In a wider field but still with a bearing on the ecology of the intertidal "foulers" is Colman and Anne Stephenson's attempt to reconcile the zonation of the more or less tideless shores of the Mediterranean with the generalised world pattern evolved by the Stephensons. They conclude that the zone subject to exposure in the Mediterranean is equivalent to that above HW neaps outside that sea and that the whole region from HW neaps to LW springs is virtually absent. This interpretation is at variance with that of the French school of thought who regard the Mediterranean shore facies as the norm to which all others should be related as variants.

The book is well produced and well edited. The standard of illustration is somewhat uneven, something to be expected with a multitude of styles employed by the different authors. This reviewer feels that in a few cases over-reduction has made figures difficult to read, at least for the more elderly reader, *e.g.*, pp. 422, 423 and 484 (Fig. 3). But these are small blemishes in otherwise good illustration.

As seems inevitable nowadays the price makes it unlikely that the book will find a place on the private bookshelf but it should be in every specialist marine biological library or any library catering for that field as a part of its services.

H. G. Stubbings

Manpower Planning. NATO Science Committee Conference. Pp. 291. London; English Universities Press. 1966. Price 55s.

This book is the proceedings of a conference entitled "Operational and Personnel Research in the Management of Manpower Systems" sponsored by the NATO Science Committee in August 1965. Its resemblance to a book is slight for it is, in fact, an expensive, poorly produced paperback with 25 authors contributing papers (one in French) which range from exhortation and education to advanced ideas in operational research and behavioural science.

The six papers in the first section deal with procurement, allocation and re-allocation of personnel, covering classical selection theory, criterion problems and a human factors programme which is sufficiently detailed to mention the effect of microelectronics on military training. A paper on the technology of military training provides the basis for the second section on production and maintenance of human capacities in manpower systems. This takes a forward look at instructional systems and clearly stimulated the other speakers in this session, particularly on the training/economics aspects.

A session on human resources and manpower planning contains some repetitive papers but is notable for a refreshing approach to the financial implications of manpower planning, the first mention in the book of career management and an attempt to link PERT systems to personnel management. Four papers on operational research aspects complete the presentation. A review paper on systems analysis techniques and some research on project staffing are directly applicable to research and development management. Surprisingly, some of the more recent advances such as the "flow of networks" approach to critical path analysis receive only a mention.

Essentially a collection of diverse discourses on mainly military matters, a path through the jargon jungle of this book (why "paradigm" and "insightful situations"?) leads to some valuable up-dating of ideas for those interested in large scale management problems, including those posed by research, development and production.

M. Hillier

The Big Battleship. By Richard Hough. Pp. 167 with 21 illustrations. London; Michael Joseph Ltd., 1966. Price 25s.

In this book the author tells the life story of H.M.S. *Agincourt* from her origins on the Tyne in 1911, when she was intended as a trump card for Brazil's hand in the South American power game, through her short period as the Turkish answer to their problems with the Greeks, to her war-time service at Scapa Flow and Jutland and finally to the breakers' yard.

Conceived by Tennyson D'Eyncourt, built (in a series of short rushes punctuated, as situations altered, by periods of inactivity) by Armstrongs and named, according to her fortunes of the moment, respectively *Rio de Janeiro, Sultan Osman I* and *Agincourt* (with the usual range of lower-deck variations), the ship's history was full of incident. The most dramatic moment was surely that which immediately preceded her appropriation by the Royal Navy on the eve of completion. For several weeks the builders had apparently been making an all-out effort to put the finishing touches to the ship, with her Turkish crew in a Naval Transport ready and waiting across the Tyne, but somehow the last of her guns were not delivered and her ammunition failed to arrive. And then, on the morning of 2nd August 1914, 24 hours before she was due to sail, she was boarded by a company of Sherwood Foresters with fixed bayonets and all the Turkish hopes and expectations came to an end.

Whether Churchill was right in taking this step, which threw the Turks into the arms of the Germans, ready and waiting on the spot at Constantinople, or to what extent the course of the war might have been altered had the ship been delivered to her purchasers, can only be a matter of opinion. But the drama of her seizure, and the subsequent exploits of the *Goeben* and *Breslau* (which the Germans offered to the Turks as consolation prizes) are brilliantly described.

The author tells the story superbly, and his capacity for research is well matched to his treatment of a fascinating subject which evidently attracts him as much as it should appeal to a wide range of readers.

There is an index of personalities and ships and, apart from a few irritating misprints on the earlier pages, the book is well set out and excellently illustrated. Your reviewer enjoyed it immensely.

A. V. Thomas

Recommendations for Ultrasonic Testing of Butt Welds. Pp. 38. London: Institute of Welding. 1965. Price 6s. 6d.

Welds are liable to contain flaws, which if not detected and repaired can lead to premature failure in service. This booklet describes the basic equipment and techniques needed for applying the versatile and inexpensive method of detection by ultrasonic testing. Compiled by a committee of experts the booklet is nevertheless clear and concise. It is thoroughly recommended for all concerned with high-quality welding.

A. P. Bennett

Books available for Review

Offers to review should be addressed to the Editor

Theory and Research in Lubrication.
M. D. Hersey.
John Wiley & Sons Inc. 1966. 140s. (No. 1494)

Axiomatic Field Theory. Vol. 1.
Editors M. Chretien and S. Deser.
Gordan & Breach, Science Publishers, Inc. 1966. $32.50. (No. 1496)

Particle Symmetries. Vol. 2.
Editors M. Chretien and S. Deser.
Gordon & Breach, Science Publishers, Inc. $35.00. (No. 1497)

A Simple Approach to Electronic Computers. Second Edition.
E. H. W. Hersee.
Gordon & Breach, Science Publishers, Inc. 1967. $7.50. (No. 1498)

Queueing Theory—Recent Developments and Applications.
Editor R. Cruon.
The English Universities Press. 1967. 65s. (No. 1499)

Elements of Mathematical Statistics. 2nd Edition.
J. F. Ratcliffe.
Oxford University Press. 1967. 18s. (No. 1500).

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